Ministry for the Environment
Manatū Mō Te Taiao

Coastal Hazards and Climate Change

GUIDANCE FOR LOCAL GOVERNMENT

New Zealand Government

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Published in December 2017 by the
Ministry for the Environment
Manatū Mō Te Taiao
PO Box 10362, Wellington 6143, New Zealand

ISBN: 978-1-98-852535-8
Publication number: ME 1341

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This document is available on the Ministry for the Environment's website:
www.mfe.govt.nz.

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About this guidance

Why is this guidance required?

Since 2001, the Ministry for the Environment has given local government guidance on how to adapt to coastal hazard risk from climate change, particularly hazard risk[1] associated with sea-level rise. The previous guidance (Ministry for the Environment, 2008a) has been widely used by local government and others involved in providing services and infrastructure to coastal areas.

This guidance is a major revision of the 2008 edition, and includes the findings and projections of the latest Fifth Assessment Report produced by the Intergovernmental Panel on Climate Change (IPCC). It also includes advances in hazard, risk and vulnerability assessments, collaborative approaches to community engagement and changes to statutory frameworks. It explains adaptive approaches to planning for climate change in coastal communities, including integrating asset management into such planning.

Hazard risk is compounding in areas adjacent to coasts, estuaries and harbours, because of the rising frequency of coastal hazard impacts and the increased exposure of people and assets as areas are developed and property values increase, together with legacy issues from past decisions. Sea level will continue to rise for at least several centuries, posing an ongoing challenge for managing the transition to more sustainable coastal communities, both globally and locally.

Elements that are vulnerable encompass a wide range of social, cultural and economic values, as well as the natural and physical environment. Finding sustainable adaptation solutions for some communities will be made more complex by:

- differences in coping capacity
- sensitivity to increasing impacts (ie, vulnerability)
- the emergence of considerable future risks.

In its 2050 challenge paper, Local Government New Zealand (LGNZ) highlights sea-level rise as one of the key factors that will greatly affect coastal communities (Local Government New Zealand, 2016b). Local government faces the enduring question of how to achieve the visions of local communities while adapting to the impacts of a changing climate.

This guidance provides a step-by-step approach to assessing, planning and managing the increasing risks facing coastal communities, along with an updated synthesis of information and tools and techniques to underpin the process. It also supports the implementation of relevant objectives and policies in the New Zealand Coastal Policy Statement 2010 (NZCPS, 2010),[2] and is complementary to *A guide to implementing the New Zealand Coastal Policy Statement 2010: Policies 24, 25, 26 & 27 – concerning coastal hazards* (Department of Conservation, 2017).

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1 Expressed as the likelihood of consequences of hazard impacts.

2 Department of Conservation, 2010.

Who is this guidance for?

This guidance is a technical document providing contemporary national guidance to local government. It enables local government to plan effectively and support the adaptation of coastal communities and council assets and services to the increasing coastal hazard risks from climate change. It will also be useful for a wider range of practitioners involved in providing infrastructure and services to coastal areas, and in new or redevelopment projects.

This guidance technical document is targeted at the policy, planning, consenting, civil defence and emergency management, asset development/management and building control functions of local government related to coastal and estuarine areas presently affected, or potentially affected in the foreseeable future, by coastal hazard risks arising from climate change.[3] It will also be applicable to practitioners who interface with those processes from outside local government, including engineers, planners, lawyers, community-engagement facilitators, policy analysts and scientists.

The guidance supports councils in undertaking collaborative processes when engaging with potentially affected communities, iwi/hapū and stakeholders during the planning and implementation processes.

A companion summary document, *Preparing for coastal change* (Ministry for the Environment, 2017) is available to help a wider audience of readers and stakeholders, including community and iwi/hapū representatives, property owners or purchasers, the public, school teachers, insurers, executives, councillors and government officials.

Conceptual basis for this guidance

The approach in this guidance differs from previous versions, and from current coastal hazard management practice, with regard to the treatment of uncertainty and the central role of community engagement in the decision-making process (see figure 1).

There is a growing understanding of the variability of climate change effects and the range of uncertainties in coastal areas that ongoing sea-level rise poses for decision-makers when considering adaptation to climate change. This guidance focuses on 'testing' responses to climate change against a range of future scenarios, before making decisions on pathways to reduce or avoid risk. Waiting until uncertainties are reduced before making decisions, or holding back on making decisions under uncertain conditions, is usually not viable or acceptable to those most exposed to the risk.

The dynamic adaptive pathways planning approach can accommodate change in the future without locking in investments that make future adjustments difficult and costly. The process can be seen as a series of interlinked pathways, where the course can change at agreed trigger or decision points within the context of a range of future scenarios. By exploring different pathways to meet objectives, an adaptive plan can be developed and implemented to include short-term actions and long-term options. This approach will help both long-term sustainability and community resilience.

[3] Coastal areas affected by coastal processes and sea-level rise now *and in the future*, and include estuaries, tidally influenced groundwater, wetlands, creeks, lowland rivers and streams, and the adjacent land margins.

Coverage of this guidance

The guidance focuses on three main types of coastal hazards that are exacerbated by climate change:

- coastal erosion caused by storms, sea-level rise and changes in long-term sediment processes and budgets (including impacts on cliffs)
- coastal inundation caused by storms and changed climate conditions, or gradual persistent inundation from high tides due to sea-level rise
- rising groundwater and salinisation in coastal lowlands caused by sea-level rise.

Adapting to coastal climate change requires much wider consideration than hazard risk management. Adaptation involves many components of the environment (including the natural environment and conservation values, as well as the built environment), and consideration of community values and aspirations that contribute to a sense of place.

This guidance provides updated information and good practice guidance, in a risk-based, adaptive management framework, to strengthen the integration of coastal hazards and climate change considerations into land-use planning, resource management, building consenting, asset and flood risk management and emergency management.

Tsunami risk management is covered briefly in this guidance – catastrophic, low-frequency events (the effects of which sea-level rise will exacerbate) are managed through emergency management systems, in addition to land-use planning. This approach will decrease the potential for rare large tsunami to dominate planning responses over all other coastal hazards, including climate change. Some planning considerations of tsunami effects are required, however, under the NZCPS 2010, which is addressed in the Department of Conservation NZCPS 2010 coastal hazards and related guidance (Department of Conservation, 2017). When planning for climate change effects in new development in greenfields or intensification in coastal areas, however, the opportunity exists to include planning elements that may reduce some of the future consequences from moderate to large tsunami events. This could enable quicker recovery from a major event, for example, by locating critical and important community facilities well back from the coast.

More specifically, this guidance:

- covers the statutory and non-statutory roles and responsibilities of local government in managing coastal hazard risk, including the effects of climate change
- sets out key principles and approaches for engaging with communities and iwi/hapū
- emphasises the importance of working collaboratively with stakeholders and affected communities throughout the decision-making process
- updates the latest guidance on sea-level rise projections to:
  - establish future exposure, vulnerability and risk
  - help with developing policy and adaptation thresholds and associated trigger levels (decision points), to be included in adaptive strategies and implementation plans and during asset design and management
- provides information on coastal hazards and the effects of climate change
- outlines approaches and good practice for coastal hazard exposure assessments
- relies on a risk-based planning framework for incorporating changing coastal hazard exposure, sensitivity to climate change and adaptive capacity considerations into risk and

vulnerability assessments, to underpin collaborative processes when assessing and evaluating response options

- promotes the development of long-term adaptive capacity for managing coastal hazard risk and uncertainties through adopting dynamic adaptive pathways that may change (switch) at various agreed decision points over time
- summarises in tables the range of available planning and policy approaches and physical response measures that can be implemented in community-specific adaptive pathways
- sets out key elements of monitoring and review needed to support adaptive pathway planning approaches, and how those contribute to adjustments of the adaptation plan.

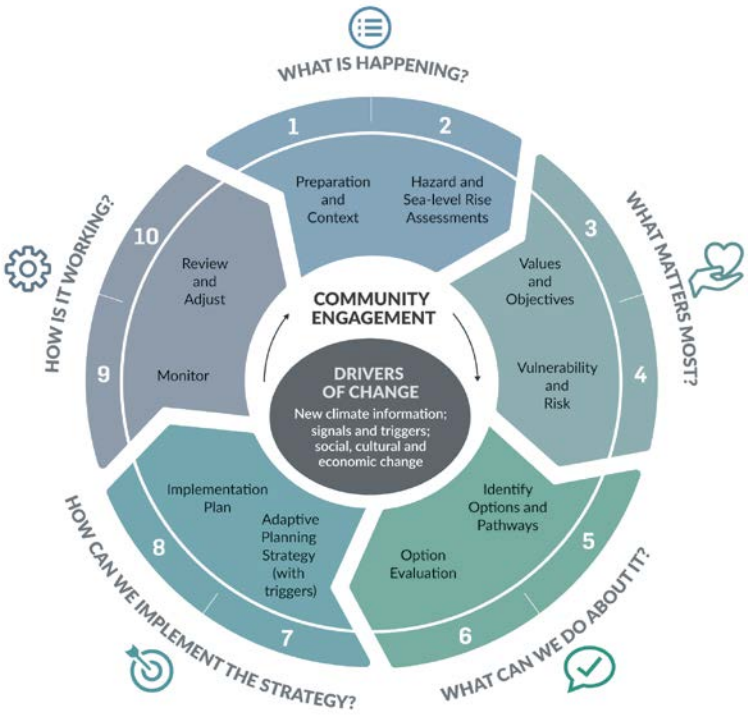
Other supporting guidance and statutory frameworks with a bearing on risk management and adapting to increasing coastal hazard risks include:

- the New Zealand Coastal Policy Statement 2010[4]
- *NZCPS 2010 Guidance Note: Coastal Hazards*[5].

Structure of the guidance

The guidance has been structured around an iterative 10-step framework. It is made up of elements to secure and implement a long-term strategic planning and decision-making framework for coastal areas potentially, or already, affected by coastal hazards and climate change effects, such as sea-level rise. The 10-step decision cycle below is structured around five key questions.

Figure 1: The 10-step decision cycle, grouped around five questions



Source: Adapted from Max Oulton (University of Waikato) and UN-Habitat (2014)

4 Department of Conservation, 2010.

5 Department of Conservation, 2017.

A. What is happening?
(includes setting the context and preparation through to undertaking sea-level rise and hazard assessments based on scenarios) – **Chapters 1–6**

B. What matters most?
(centred on values and objectives: people and asset service delivery and undertaking risk and vulnerability assessments) – **Chapters 7–8**

C. What can we do about it?
(identifying and evaluating options) – **Chapter 9**

D. How can we implement the strategy?
(secure and implement an adaptive planning strategy) – **Chapter 10**

E. How is it working?
(monitoring and regular reviews and possible adjustments) – **Chapter 11**

Community engagement is linked to a number of the steps, and additional iterations of the process can be driven by new climate information, reappraising early signals and triggers (decision points) and social, cultural and economic change.

Supporting tools and resources are listed in chapter 12, and background statutory and science information is provided in the appendices, along with supplementary information on various coastal hazards.

A full glossary of terms and abbreviations is provided at the end of this guidance.

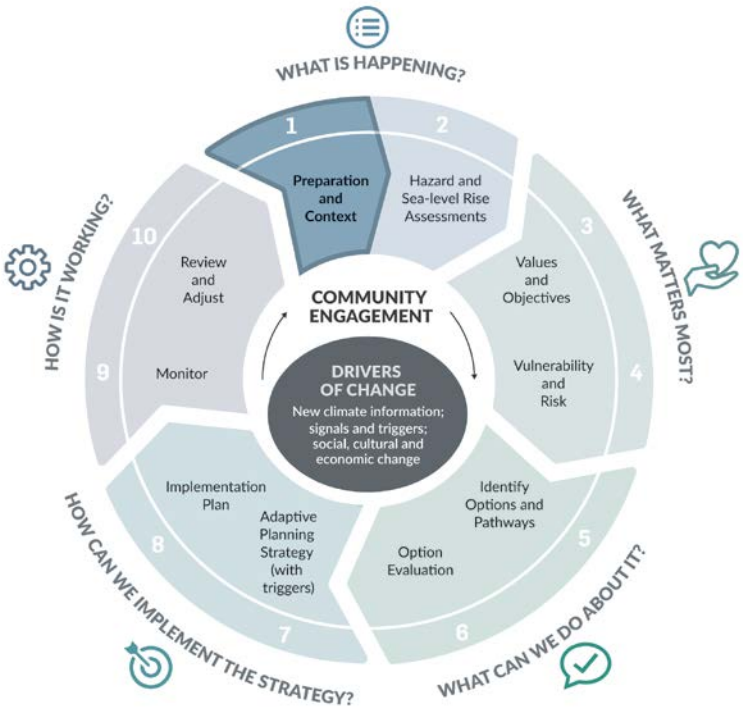
The guidance also includes appendices that contain further information about the relevant legislation, science and the adaptive planning process.

Section A: What is happening?

1 Setting the context and preparation

Chapter 1	**Chapter 1 covers:** • context and challenge around the compounding coastal hazard risk • why we need to adapt in coastal areas • planning and risk management context, including dealing with uncertainty • preparation for adaptation (see figure 2).
Step 1	**Key tasks** a. Establish a multi-disciplinary adaptation team, covering a range of skill sets. b. Carry out preparatory tasks around understanding the scope of the changing risk and local community context. c. Agree on how the team will engage with the community, iwi/hapū and stakeholders, the overall planning approach, and mobilise resources.

Figure 2: Step 1 in the 10-step decision cycle: What is happening? – preparation and context



1.1 Compounding coastal hazard risk

Much of New Zealand's urban and peri-urban development is situated in coastal areas and around harbours, estuaries, creeks and lowland rivers.

The community anticipates that the land along the coastal margin will persist permanently, and that those living there will be safe from natural coastal hazards (apart from rare tsunami or storm events). Sea-level rise from climate change challenges this perception. Some historic development is located in areas that are already exposed to natural hazards, such as coastal erosion and inundation, however. Main roads, maritime structures and other key infrastructure are also located in coastal areas, as are amenity areas and environments valued

by the community, such as parks and reserves, wetlands and bird nesting sites. Risk[6] is increasing in coastal areas due primarily to sea-level rise, in combination with:

- ongoing development and associated population growth
- rising property and asset valuations
- increasing coastal hazard exposure from storm surges, king tides and erosion, on the back of an ongoing sea-level rise
- the nature of human responses to the impacts of hazards.

The impact of climate change in some coastal areas will be amplified by the:

- effects on social, cultural and economic values
- coping capacity of the community
- sensitivity of natural and physical environments (usually expressed as vulnerability).

Coastal hazard risks will be further exacerbated in the future by rising sea levels and increased frequency of damaging or disruptive coastal hazards. For example, a modest sea-level rise of 0.3 metres to 0.4 metres (possibly reached by 2050–60) will convert a present-day rare storm-tide inundation event (eg, with a 1 per cent annual exceedance probability (AEP)) to an event that will occur on average once a year (Parliamentary Commissioner for the Environment, 2015; Stephens, 2015).

As a result, risk management and planning must recognise there is both a changing risk exposure from coastal storm and erosion events, and also high level of uncertainty regarding future rates of sea-level rise, including the onset of polar ice sheet instabilities, into next century.[7]

Present and future coastal risk exposure in low-lying coastal areas was evaluated nationally (see box 1) in the Parliamentary Commissioner for the Environment's 2015 report (Bell et al, 2015; Parliamentary Commissioner for the Environment, 2015). Overall, while only 0.6 per cent of New Zealand's land area has an elevation within 3 metres of the mean high water spring tide (MHWS) mark, these areas account for 6 per cent to 7 per cent of the replacement costs for all New Zealand buildings (NZ$52 billion[8] (in 2011)) and 6.6 per cent (281,900 residents (2013 Census)) of the total resident population (Bell et al, 2015).

Climate change will not introduce any new types of coastal hazards, but it will increasingly change the nature and extent of the impact from coastal hazards compounded by SLR. It will exacerbate and increase the frequency of coastal erosion and inundation, and raise groundwater levels in coastal areas and inland low-lying coastal plains, increasing the risk from coastal hazards to exposed coastal development, and creating risks not previously experienced; for example, ground liquefaction risk as sea level continues to rise.

Climate change is already starting to impact how our coastal communities live and function, but sea level will continue rising for several centuries, even if global greenhouse gas emissions are reduced; this will only reduce the rate of rise.

Ongoing sea-level rise will lead to irreversible impacts at the coast. Because many land-use planning and asset and infrastructure decisions made today have long lifetimes because of the permanency of development (eg, subdivision, buildings and infrastructure), planning for adaptation at the coast needs to start now.

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6 Expressed as a combination of likelihood and consequence.

7 Especially if the global-mean temperature exceeds around 2°C above pre-industrial levels.

8 Defined as a thousand million dollars.

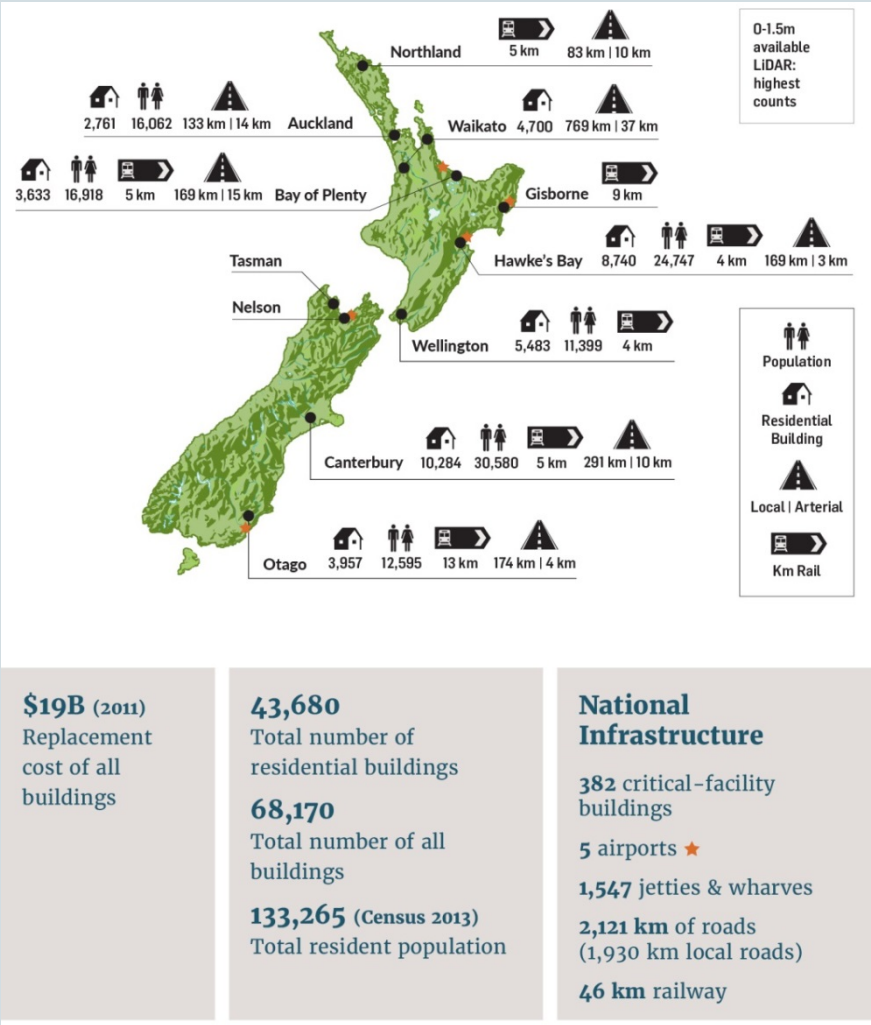
Local Government New Zealand, in its 2050 challenge discussion paper (Local Government New Zealand, 2016b), highlights sea-level rise as one of the key shifts that will heavily affect coastal communities. One of the enduring questions local government faces is how to achieve the visions of communities while adapting to the impacts of a changing climate.

BOX 1: NATIONAL COASTAL RISK EXPOSURE

As background to the 2015 Parliamentary Commissioner for the Environment's report on *Preparing New Zealand for rising seas*, NIWA used coastal elevation bands from 0 to 3 metres above mean high water spring (MHWS) as a proxy for New Zealand's risk exposure, using high-resolution LiDAR[9]-derived topography where available. Areas that are both low lying and close to the coast are, in general, the most vulnerable to sea-level rise.

The infographic shows the higher levels of coastal risk exposure in different regions, in terms of resident population, buildings, roads, railway, airports and jetties and wharves for land elevations less than 1.5 metres above MHWS at the coast. Results at the bottom have been aggregated from regional totals for regions where LiDAR data was available.

The highest coastal risk exposure is in Canterbury and Hawke's Bay, with Waikato having the highest length of road network exposed, mostly local roads.



Source: Bell et al (2015), including the infographic; Parliamentary Commissioner for the Environment (2015)

9 Light Detection and Ranging (LiDAR) uses a laser scanning system usually mounted on an aircraft with height accuracies down to 0.1 metres.

1.2 Why we need to adapt in coastal areas

While much of the global focus and discussion has been on mitigating (reducing) greenhouse gas emissions, adaptation has now become an integral part of climate change policy worldwide.

In New Zealand, the major impacts of climate change that will require significant adaptation will be coastal hazards, drought and floods (Reisinger et al, 2014). This guidance focuses on adapting to the increasing coastal hazard risk from climate change.

Climate change is already unavoidably affecting the climate–ocean system. In the context of coastal impacts, the inertia in global sea-level response, with very long response times (centuries to millennia), poses an increasing commitment to sea-level rise that will materialise for coastal areas globally in decades and centuries to come. While substantial global emission cuts in the future could reduce the rate and the ultimate magnitude of sea-level rise, a long-term commitment to a rise in sea level has already been built into the climate–ocean system, resulting in a substantial 'adaptation deficit' for coastal areas that will need to be addressed.

The scale of the adaptation needed will largely be defined by the future development of the world's economy, energy use, global land-use patterns, population growth and resolve to swiftly reduce greenhouse gas emissions, all of which contribute to future uncertainty. Society may have to respond and adapt to rises in global mean temperature of 2–4°C or more above pre-industrial levels, and to sea-level rises of 0.5–1 metre or more over the next 100 years.

Adapting locally and regionally to such changing conditions is challenging at best (Smith et al, 2011), and some areas are likely to eventually face practically insurmountable physical limits due to frequent hazard impacts (Werners et al, 2013).

Recent global initiatives (started by the Intergovernmental Panel on Climate Change (IPCC) Special Report (IPCC, 2012), followed by the Paris Conference of the Parties (COP21) climate change agreement (UNFCCC, 2015) and the Sendai Framework (United Nations, 2015)), have attempted to bridge the gap between present-day disaster risk management and climate change impacts – often treated separately. Planning, and developing future resilience through adaptation, will involve a transformation of our understanding of the unpredictability and range of possible climate change futures. On the other hand, public willingness to act to mitigate climate change through emission reductions is based on growing experience and understanding of the impact of disasters already linked to climate change (Lever-Tracy, 2016).

1.3 Planning and risk management context

Land and property values in front-line exposed coastal areas may eventually reduce over time, as:

- community understanding of risks and consequences increases
- frequency of damaging events increases
- investment finance becomes more difficult to obtain
- insurance costs rise.

Over time, however, communities will be left increasingly exposed, with vulnerable assets and a stock of private and public investment (eg, buildings, roads, utility services, sea walls) for which difficult decisions will be required – remove, relocate or demolish, or invest substantially to protect. The places and environments valued by people will also be exposed to increasing impacts, and vulnerable groups and those without the capacity to move will be particularly affected. The likely scale, extent and impact of the evolving increase in coastal risk will be unprecedented across New Zealand (leaving aside large geological hazard events).

As well as addressing legacy issues from past decisions, communities will need to ensure that present knowledge of the increasing risk and understanding of the evolving consequences are embedded in key decisions. The risks to future communities, and their ability to address them, should not be made worse by decisions taken now.

The New Zealand Government is a signatory to the *Sendai Framework for Disaster Risk Reduction*[10] (United Nations, 2015) for the 15-year period 2015–30, contributing to the achievement of seven global targets for risk management and reduction, which include climate change effects. Internationally, managing disaster risk is now framed intentionally around 'risk reduction', rather than the prevailing response and recovery approach after each hazard event. The United Nations Framework Convention on Climate Change (UNFCCC) and the COP21 Paris Agreement (UNFCCC, 2015), along with the IPCC Special Report (IPCC, 2012), take a wider view of how climate change interacts with current hazard risk (including ongoing sea-level rise) that occurs outside so-called disaster 'events'.

Avoiding increasing the risk in coastal areas from hazards and the effects of climate change are, along with encouraging redevelopment that reduces risk, also embedded in the New Zealand Coastal Policy Statement (NZCPS 2010)[11] (eg, Objective 5 and policies 24–27). These and other policies in the NZCPS 2010 form the core planning and hazard risk management context for this guidance, under the umbrella of the Resource Management Act 1991 (RMA). Guidance for the hazard assessment and management provisions of the NZCPS 2010 is provided by the Department of Conservation (2017). Adaptation to coastal climate change also involves a broader consideration, however, of how communities, council and utility services can function and cope with a changing climate state and associated sea-level rise.

The wider statutory framework relevant for managing coastal environments and roles, and the responsibilities of local government in that framework and particularly for adaptation to climate change, are outlined in chapter 2 and appendix A, with a summary of relevant court cases provided in appendix B.

1.3.1 Dealing with uncertainty

Several interacting sources of uncertainty mean that some aspects of future climate change and its impacts on coastal areas will not be known with any precision for the foreseeable future (adapted from Kunreuther et al, 2013).

- Some uncertainties involve the path of global socio-economic development, land use, population growth and emissions.
- Other uncertainties involve incomplete understanding and modelling of the climate–ocean–ice system and broader feedback processes, and how that translates to sea-level rise and associated effects on coastal-hazard sources (eg, waves, storms, changes in sediment budgets).
- A final set of uncertainties relate to how assets at risk (exposure) will change in physical and monetary terms, and the level of protection that can be implemented to reduce their vulnerability to potential losses through adaptation measures.

This guidance encourages transparency and consideration of the full spectrum of uncertainty – including known unknowns and unknown unknowns ('black swans') – and how to factor these into more adaptive planning that enables flexible decision-making for the future, whatever impacts evolve. The implication of these interacting sources of uncertainty is that choosing

[10] Adopted at the third United Nations World Conference in Sendai, Japan, on 18 March 2015.

[11] Department of Conservation, 2010.

adaptive climate policies and pathways is intrinsically an exercise in planning and risk management, engaging with stakeholders and communities, with a focus on planning to reduce the consequences for a range of possible coastal futures. Waiting until uncertainties are reduced before making decisions, or doing nothing, is usually not viable or acceptable to those most exposed to the risk.

1.3.2 Risk-based approach in a changing coastal hazard exposure

The international standard, Risk Management – Principles and Guidelines (AS/NZS ISO 31000:2009), provides a consistent, globally accepted framework for risk assessments, and the subsequent management of identified risks from any human or natural hazard exposure.

The standard provides a high-level definition of risk as the "effect of uncertainty on objectives". 'Effect' here is defined as a deviation from the expected (negative or positive); 'objectives' can encompass a range, such as financial, health and safety, resilience and environmental goals, and can be applied at different scales and through different processes, such as strategic, regional, organisational or at project level.

This high-level definition of risk covers understanding and addressing the effects of uncertainty on future objectives and values for coastal areas.

In practice, risk is typically assessed by combining the probability of an impact occurring (or its 'likelihood') with the 'consequence' of the impacts, with the consequences related to the exposure and vulnerability of assets or people. Climate-change risk assessments in various forms have become commonplace in adaptation planning globally, including at district, regional and national scales (eg, *UK Climate Change Risk Assessment* (Department for Environment, Food and Rural Affairs, 2012), *Climate change risks to coastal buildings and infrastructure: A Supplement to the First Pass National Assessment* (Department of Climate Change and Energy Efficiency, 2011), *Preparing New Zealand for rising seas: Certainty and uncertainty* (Parliamentary Commissioner for the Environment, 2015) and *Hawke Bay Coastal Strategy: Coastal risk assessment* (Tonkin+Taylor, 2016b)).

The likelihood component of risk assessment and management is particularly difficult to quantify for coastal areas, however, in the context of ongoing sea-level rise with widening uncertainty bounds over time. Current scientific and socio-economic studies cannot assign a probability to any particular sea-level rise occurring in any given timeframe. Therefore, when assessing the risk associated with SLR in risk assessments, the most important component to focus on is the assessment and evaluation of consequences, as shown in guidelines adopted by the City and County of San Francisco (City and County of San Francisco Sea Level Rise Committee, 2015) and California Coastal Commission (2015).

Likelihood can be determined for coastal hazard events, as currently used in risk assessments (eg, 1 per cent annual exceedance probability or AEP), along with allowances for any sensitivity of those hazards to climate change, before combining with sea-level rise. While likelihood cannot be quantified for sea-level rise, the focus should be on 'testing' responses to climate change against a range of future SLR scenarios in combination with coastal hazards (chapter 6), before evaluating and making decisions on pathways to reduce or avoid risk (chapters 9–10).

A risk-based approach underpins this guidance for planning and decision-making, focusing on consequences and dealing with likelihood, depending on the hazard being assessed (eg, storm-tide levels or erosion cut back). In the case of sea-level rise, it takes into account the type of development or activity, considering a range of future scenarios. For new developments (eg, greenfields), there is already national policy direction in the NZCPS 2010 (Objective 5) to ensure such development is located away from areas prone to coastal hazard risk (including the effects of climate change) (Department of Conservation, 2010).

Where existing development and assets are involved, Policy 27 (NZCPS 2010) outlines strategies for developing options to reduce coastal hazard risks, including "identifying and planning for transition mechanisms and timeframes for moving to more sustainable approaches" (Department of Conservation, 2010). For existing (legacy) development, consequences can be established through risk and vulnerability assessments, and the dynamic adaptive pathways approach identifies the conditions under which policies and measures would no longer reach the objectives of the adaptive plan. These can be expressed as adaptation thresholds and triggers (ie, decision points with sufficient lead time), with sea-level rise and hazard scenarios used to test the sensitivity of a response or pathway.

Such adaptive frameworks can be used to:

- assess the risk consequence implications for a range of future sea-level rise and climate change scenarios
- identify the circumstances and timeframes in which unacceptable levels of risk may be reached
- express those circumstances as decision points where and when a new pathway is needed.

Through long-term monitoring, including of sea-level rise and the frequency of hazard events that transpire, the likely timeframe for switching to the next adaptation measure can be reappraised and updated.

Having a full range of scenarios of possible future outcomes to stress test response options gives the ability assess whether enough adaptation is being done, or is possible in the future. A standard set of scenarios (climate, socio-political and economic) for New Zealand would help decision-makers consider what can be done now and in the future, and enable more manageable decision-making as the risk profiles change by embedding flexibility in future pathway options so that adjustments can be made. Work is under way to develop such scenarios.[12]

Risk and vulnerability assessments under a changing climate are, of course, not static – existing risks will change, and new risks will arise over a wider area over time. There will be future physical, social and economic consequences, even following implementation of adaptation measures, which will require further adaptation (California Coastal Commission, 2015).

This understanding of changing risk is central to considering how to adapt to climate change related coastal hazards, now and in the future. It also highlights the importance of considering the broader vulnerability of communities (including coping capacity), and the nature and costs of adjustment and transfer between different pathways.

[12] Research Aim 5 of the Climate Change Impacts and Implications research programme funded by the Ministry of Business, Innovation and Employment (Frame B, Reisinger A. 2016. Exploring options for New Zealand under different global climates. Synthesis Report RA5. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100. MBIE Contract C01X1225. 19pp. Available from ccii.org.nz). This work is also included in the Deep South Challenge Project *Supporting decision-making using adaptive tools in a changing climate*.

1.4 Preparation for adaptation to coastal climate change

Adaptation to climate change is an iterative process

The 10-step decision cycle (figure 1) is an iterative process that will start in different places, depending on the:

- problem
- stage you are currently at in the decision cycle
- drivers of change, such as new climate change information
- changes needed in triggers (decision points) for switching adaptation pathways
- social, cultural and economic change.

This section assumes you are at step 1 of the decision cycle. Adaptation to climate change, especially for coastal areas facing ongoing SLR, is a complex area of planning and decision-making that affects people's lives and livelihoods and will challenge the provision and maintenance of council services and utilities. It is important from the beginning to canvass widely the potentially affected communities, iwi/hapū and stakeholders, to understand the community context and factors shaping risk, the issues and the actors and their relationships. Interactions can be initiated by seeking local knowledge and information (such as photographs of changes and past events), and by identifying what communities value about their community and environment (step 3 of the decision cycle).

1.4.1 Establish the team

A multi-disciplinary team will be necessary to implement the 10-step decision cycle outlined in this guidance. Historically, coastal hazard and climate change responsibilities have rested primarily with coastal hazard analysts and planners. A wider set of expertise, skills, knowledge and information will be required, however, to navigate the coastal adaptation challenge, because of the pervasive nature of the impacts and implications within the community and across many local government functions and different sectors (eg, utilities, infrastructure, insurance, banking and so on) (see box 2).

Key questions to consider when establishing a team include:

1. What sorts of leadership, integration and relationship management and engagement (enabling) skills will be needed?
2. What sets of core knowledge are necessary (eg, technical expertise, planning and policy, iwi/hapū knowledge, social science techniques, engagement and possibly independent facilitation skills)?
3. What networks and linkages can be drawn on or established to obtain access to skills and knowledge the team requires but does not possess?

BOX 2: SKILLS, DISCIPLINES, KNOWLEDGE SETS TO CONSIDER IN AN ADAPTATION TEAM

	Skills, disciplines and knowledge
Enabling skills	Leadership, integration across portfolios, engaging with public engagement, strong iwi/hapū relationships and links.
Knowledge sets	Coastal management, coastal hazards, planning and policy, civil defence and emergency management, legal, economics, community engagement, facilitation, iwi/hapū engagement protocols and/or representatives, indigenous knowledge, biodiversity, roads and transport, asset management, reserves and parks, hydrology (includes groundwater), engineers, surveyors, adaptation specialists, science communicators, emergency response organisations.
Access to networks and links	Historical information, institutional knowledge. Access to networks and liaison with key businesses, industries, utility and infrastructure providers, other local authorities, iwi/hapū groups, local community representatives and private/public property owners. Key individuals and groups who are strongly networked with the core team.

Modified from the *Irish Local Authority Adaptation Strategy Development Guideline* (Gray, 2016).

Note: A single team is unlikely to possess all the skills and knowledge needed, but can establish strong links and networks with others who may be seconded into the team as required. These networks will facilitate access to, and sharing of, knowledge and skills held in other places.

1.4.2 Preparatory tasks

Once the multi-disciplinary team is established, much of the preparatory work will revolve around understanding the **scope** of the changing risk, and the local community **context**, before formulating and resourcing a working plan.

The local community context includes the key interests, and their relationships with the coastal issues and how they perceive them, so that a formal and legitimate engagement process can be developed for subsequent involvement at step 3 of the decision cycle.

Gathering important contextual information (including local knowledge) and making broad choices around the tools, approaches and community engagement are essential steps in preparing for the hazard, risk and vulnerability assessments, and the development of subsequent adaptive responses.

A set of possible tasks at the formative stage of setting the context and preparation for coastal adaptation projects follows.

Preparatory tasks: Setting the context and the scope of the risk

1 Establish the team and agree on the best way to work together (see previous section).

2 Establish the need to reduce coastal risk (including the effects of climate change).

- Identify the scope of coastal hazard risk (eg, extent of low-lying coastal areas, areas of potential groundwater and drainage effects, previous hazard events and reports).
- Define communities and the factors shaping risk.
- Perform stocktake of available information (eg, demographics, social, physical processes, monitoring data, relevant plans and policies, iwi management plans, topographic elevation data (preferably LiDAR[13]), aerial imagery (which is useful for visualising consequences of climate change during community engagement)).
- Make connections with potentially affected communities (eg, seek out local knowledge on what people value about the area, open days on the proposed project).

3 Agree how your team will engage with the community, iwi/hapū and stakeholders.

4 Agree on the planning approach and mobilise resources.

- From the contextual information (see box 3), decide on the overall approach, for example, planning, assessments (hazard, risk, vulnerability) and adaptive framework.
- Develop a case for the project within and between councils, and secure funding and a planning mandate (eg, long-term plan).
- Develop a work programme.

Adapted from Glavovic (in press).

BOX 3: ESTABLISHING THE CONTEXT – KEY CONSIDERATIONS

What is the problem or objective(s) that need(s) to be addressed?

Where does the need to make a decision come from?

What are the primary drivers behind the problem?

What is the planning timeframe and/or realistic 'permanency' timeframe?

What are the boundaries, both spatially (ie, potential area affected by the hazard or decision) and temporally (ie, the time period) over which the decision will be applied?

What constraints and decision criteria can be identified?

What is the extent and quality of data and information available?

What is the level of risk analysis to be adopted?

What legislative or policy constraints or requirements may apply?

What information on similar decisions and other guidance is available for this issue?

Have coastal hazards and climate change been included in the decision-making process before, or been accounted for at a higher level (eg, policy or strategic)?

How will the hazard, risk and vulnerability assessments be used in the decision-making process?

What resources are available to aid the risk assessment and decision-making?

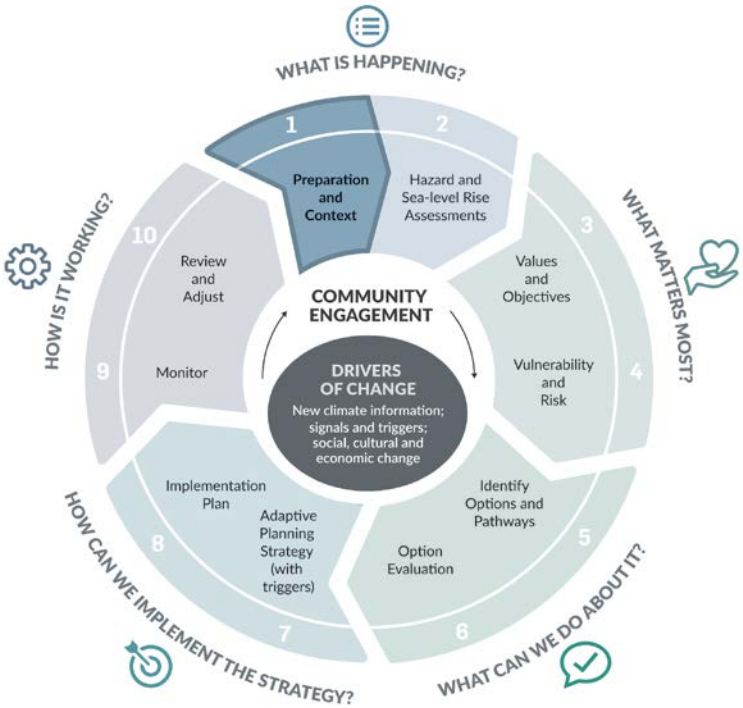
Source: Adapted from Ministry for the Environment (2008a) p 50

13 Laser scanner surveys; Light Detection and Ranging (LiDAR).

2 Role of local government

Chapter 2	**Chapter 2 covers:** • planning context for coastal risk management • leadership in the local context • application of the New Zealand Coastal Policy Statement 2010 • principles for local government • adapting to climate change and adaptive pathways in planning context.
Step 1	**Key tasks** a. Develop understanding of the statutory framework and relevant court cases (also appendices A and B). b. Devolve local government responsibilities to appropriate level. c. Familiarise adaptation team with various principles for local government including commitment to consultation and engagement. d. Determine ways to leverage coastal adaptation opportunities through the current resource management and asset planning processes (also chapter 10).

Figure 3: Step 1 in the 10-step decision cycle: What is happening? – preparation and context



2.1 Responsibilities devolved to the appropriate level

The purpose of local government is:

a) to enable democratic local decision-making and action by, and on behalf of, communities; and

b) to meet the current and future needs of communities for good-quality local infrastructure, local public services, and performance of regulatory functions in a way that is most cost-effective for households and businesses.

Source: Section 10(1), Local Government Act 2002

In adapting to the effects of climate change in New Zealand, local government is at the front line. Local government is largely responsible for civil defence, regional and district land-use planning[14] and major community infrastructure. The avoidance or mitigation of natural hazards is one of local government's core services, to which it must have particular regard when undertaking its functions and performing any of its roles.[15]

Internationally, local government has long had a focus on climate change, sustainable development and community resilience.[16] In this environment, communities are seen as the most effective level for making decisions and taking actions to manage exposure to local natural hazard risks.

Increased recognition of the long-term and growing effects of climate change has coincided with an increasing emphasis on the need for local government to make sound decisions in managing community resources. Where it can, it is expected to help reduce the risk exposure of communities to natural hazards (including those associated with climate change), now and into the future, and to help build resilient communities. The complexities of these responsibilities have been set out in Local Government New Zealand's (LGNZ's) 'think piece' (Local Government New Zealand, 2014). Local government's contribution to managing natural hazard risk and the effects of climate change is fundamental to achieving sustainable management that meets the needs of current and future generations.

The main responsibilities of local government in relation to natural hazards are set out in the 'think piece', as follows:

Regional councils are charged with:

- controlling the use of land for the purpose of the avoidance or mitigation of natural hazards (section 30 RMA 1991[17]), unless otherwise specified in the RPS;[18]
- setting out (in the RPS) objectives, policies and methods relating to the avoidance and mitigation of natural hazards and specifying responsibilities for functions relating to natural hazards;
- addressing natural hazards risk in carrying out its other RMA planning and consent processing functions;
- coordinating regional CDEM[19] Groups (and participating on such groups); and

14 Including integrated land use and infrastructure planning, often referred to as spatial planning. See UN-Habitat, 2015.

15 Section 11A, Local Government Act 2002 (LGA).

16 The Rio Declaration (United Nations, 1992) and the Sendai Framework (United Nations, 2015).

17 Resource Management Act 1991.

18 Regional policy statement.

- developing and maintaining soil conservation and river control (flood protection) schemes.

Territorial authorities are charged with:

- controlling the effects of the use of land for the avoidance or mitigation of natural hazards (section 31 RMA 1991)
- exercising discretion under section 106 to refuse a subdivision consent where there is a significant risk from natural hazards
- controlling building under the Building Act by issuing consents for buildings that comply with the Building Code
- issuing LIMs[20] under the LGOIMA[21] and PIMs[22] under the Building Act
- participating in regional CDEM Groups.

All of these roles and responsibilities apply in the coastal environment, as well as elsewhere in the region or district. The Resource Management Act 1991 (RMA), however, provides local government with particular responsibilities in relation to the coast, and the coast is one of the areas where climate change effects are particularly likely to be experienced. Under the RMA, the management of significant risks from natural hazards must be recognised and provided for (section 6(h)[23]), and all decisions must have particular regard, among other things, to the effects of climate change (section 7(i)).

These roles and responsibilities, and the relationships between the various statutes, are explained further in appendix A. A summary of relevant court cases that may help with interpretation in specific circumstances is presented in appendix B.

While many of these responsibilities relating to natural hazards will continue into the future on a business-as-usual basis, others, particularly those undertaken under the RMA (and the Civil Defence Emergency Management Act 2002 (CDEMA)) in the coastal environment, are being undertaken in a changing context. Estimates for the global impacts of climate change in terms of sea-level rise are available, and trends in the near term (mid-century) are known with reasonable confidence; however, the implications of what may seem manageable and consistent trends become less reliable in the future and occur across wide bands, depending on the sea-level rise scenario (see chapter 5). The local implications of sea-level rise and the complex interrelationship of weather events, coastal geomorphology and coastal processes, will vary from place to place and over time. In the more distant future there is little certainty, with the potential consequences of climate change in coastal areas varying considerably across different scenarios.

As explained in the Parliamentary Commissioner for the Environment's 2015 report *Preparing New Zealand for rising seas: certainty and uncertainty*:[24]

> It is certain that the sea is rising and will continue to do so for centuries to come. But much is uncertain – how rapidly it will rise, how different coastal areas will be affected, and how we should prepare.

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19 Civil defence emergency management.

20 Land information memoranda.

21 Local Government Official Information and Meetings Act 1987.

22 Project information memoranda.

23 Added on 19 April 2017: Resource Legislation Amendment Act (2017 No 15).

24 Parliamentary Commissioner for the Environment, 2015, p 5.

2.2 Leadership in the local context

Local government bodies undertake their responsibilities in real time, including addressing situations inherited on the basis of past decisions (legacy issues). The risk exposure information in box 1 translates into a major challenge for local government, as well as for private and public asset owners, over the next century. Local government's responsibilities, which encompass "present and anticipated future circumstances",[25] put an emphasis on dealing with legacy issues as well as managing wisely for the future.

Local government will need to identify communities that are vulnerable to the effects of sea-level rise and address the implications. Understanding the vulnerability of different areas and communities relies on information about, and understanding of, the implication of sea-level rise and other aspects of climate change at the community level (see chapters 3 to 8 of this guidance). As local government's planning and decision-making responsibilities stretch into the future, identifying vulnerability has a time dimension. Local government needs to understand that climate change effects represent risks to communities near the coast and, in some cases, further inland that will increase over time. Different effects of climate change will be felt by vulnerable communities first (through local inundation, groundwater ponding, shore-protection structures that are regularly damaged, wave overtopping and erosion, and increasing problems in maintaining coastal roads and underground services), and some are already on the front line. The extent of the risks to communities in the more distant future can only be understood within broad boundaries at any time.

The need to replace, protect, modify or remove buildings and infrastructure in vulnerable coastal areas exposed to natural hazards, including the increasing hazards associated with climate change, is a major responsibility, where local government (along with central government) will have leadership roles. As explained by central government, referring to long-term risk reduction:[26]

> As most hazard events occur at the local or regional scale, New Zealand's hazard risk management and CDEM [civil defence emergency management] planning frameworks place a strong emphasis on local initiatives for risk reduction. Individuals, communities and local government are best placed to decide on the management options suited to them, for example through land-use planning and building control activities.

The inertia (or sunk investment) built into existing urban systems will call for careful management. The drivers to intensify and maximise efficiency of land use and infrastructure in such areas must be seen in the wider context of changing risk and associated long-term costs. Local government is responsible for ensuring that current risk exposure is not increased unmanageably in the future. Particular effort is needed to ensure that existing developed areas are carefully managed, and new development areas are not located where they will add to the existing legacy of risk exposure. This will become increasingly difficult to manage without major community cost (in both social and monetary terms), or risk transfer from private interests to the public (see chapter 10).

Climate change considerations are adding new complexity to local government's roles. The local government purpose of "democratic local decision-making and action by, and on behalf of, communities",[27] means that the inherent tension between private rights and public

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25 Section 10(2)(c) LGA.

26 Ministry of Civil Defence and Emergency Management, in terms of risk reduction, see www.civildefence.govt.nz/cdem-sector/cdem-framework/the-4rs/reduction/local-and-regional-hazard-risk-reduction/.

27 Section 10(1) LGA.

responsibilities can become challenging. Active engagement of communities in major land use and infrastructure decisions is needed now, more than ever. Community involvement is a thread that runs right through this guidance.

The need to make effective decisions that build risk assessment into an uncertainty framework may be challenging, however, there are accepted ways of presenting risks and uncertainty, and well-developed frameworks for making decisions that can help these processes (see chapters 9 and 10 of this guidance).

2.3 New Zealand Coastal Policy Statement 2010

The New Zealand Coastal Policy Statement (NZCPS) provides national policy direction for coastal management in New Zealand. It is the only policy statement at the national level that is required under the RMA, and it applies to all regional and district RMA planning and decision-making in the coastal environment. Its scope extends beyond the marine margin to encompass the coastal environment. In accordance with the purpose of sustainable management in Part 2 of the RMA, and specific matters in section 6 of the statute, the policy approach of the New Zealand Coastal Policy Statement 2010 (NZCPS 2010) is to enable people and communities to provide for social, economic and cultural well-being and health and safety, and to protect coastal uses and values that are recognised as matters of national importance.[28]

The Minister of Conservation is responsible for the preparation and recommendation of the NZCPS. The Department of Conservation has published guidance on coastal hazards and related policies.[29]

Objective 5 of the NZCPS 2010 integrates coastal hazard risk and climate change. It directs that climate change be taken into account in managing coastal hazard risk, and that management of these risks be done proactively by:

- locating new development away from areas prone to such risks
- considering responses, including managed retreat, for existing development in this situation
- protecting or restoring natural defences to coastal hazards.[30]

The wording of Objective 5 is directive – "to ensure" that coastal hazard management is undertaken in this way. It requires a considered and justified response from decision-makers.

The guidance in the NZCPS 2010 objectives (figure 4) is outlined in a range of policies that help local authorities step through the logic of the national policy guidance, as set out in the following paragraphs. The full text for policies 24 to 27 is in appendix A, box A.3.

Policy 24 requires identification of coastal areas that will potentially be affected by coastal hazards over at least 100 years,[31] with priority for identifying areas at high risk. The policy outlines the range of influences contributing to risk exposure, which include matters addressed in this guidance. Importantly, regard must be had to "national guidance and the

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28 Objective 6, NZCPS 2010, Department of Conservation, 2010.

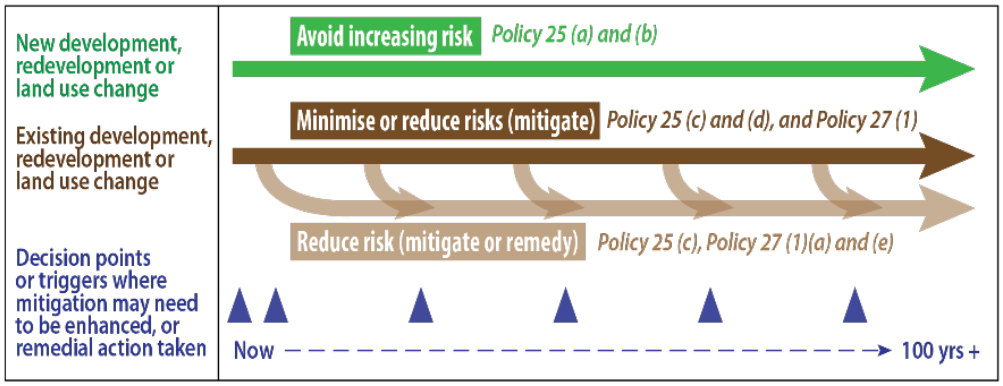
29 *A guide to implementing the New Zealand Coastal Policy Statement 2010: Policies 24, 25, 26 & 27 – concerning coastal hazards*, Department of Conservation, 2017.

30 Objective 5, NZCPS 2010, Department of Conservation, 2010.

31 The range of hazards identified includes tsunami. This is not addressed specifically in this guidance, but a similar approach is required. Planning for climate change-related coastal hazard risk reduction will also help with managing effects of tsunami.

best available information on the likely effects of climate change" in identifying areas potentially affected by coastal hazards and the level of exposure to risk.[32]

Figure 4: Broad New Zealand Coastal Policy Statement 2010 decision context for coastal areas exposed to coastal hazards and climate change



Note: the terminology refers to the Resource Management Act 1991 section 5(2)(c) requirements to manage the adverse effects of activities on the environment by steps that "avoid, remedy or mitigate".

Policy 25 sets out the framework for policy development and decisions by local authorities when areas potentially affected by coastal hazards have been identified in terms of Policy 24.[33] This policy establishes direction on several matters, including:

- avoid increasing the risk of harm from coastal hazards – in social, environment and/or economic terms
- avoid change in land use[34] or redevelopment that would increase the risk of adverse effects from coastal hazards
- encourage changes in land use or redevelopment that would reduce the risk of adverse effects from coastal hazards, including measures that build in resilience (through recoverability or relocation), or involve managed retreat or abandonment
- encourage infrastructure to be located away from hazard risks where practicable
- discourage hard protection structures and promote alternatives, including natural defences.

The term 'avoid' is strongly directive language for local authorities faced with pressures for new coastal developments (greenfields development) and pressures for intensification in areas of both long-term and short-term coastal risk exposure. The terms 'encourage' and 'discourage' allow for a less prescriptive response in terms of policy, planning and public investment for existing areas (which may also include methods such as community education and civil defence).

Policy 27 effectively expands on Policy 25 and sets out how to approach planning and decision-making in areas of significant existing development that are exposed, or will become exposed, to coastal hazards. In preparing to take action under Policy 25(c), (d) and (e) for such areas, Policy 27 addresses strategies. Under this heading, options to reduce risk over time must be identified and considered. Among the long-term options specifically identified in the risk management context are the relocation or removal of existing development and existing

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32 This recognises the changing risk of exposure to climate change effects in coastal areas and the need to take a long-term view.

33 There will always be debate about 'how much' information is necessary before taking action. This is addressed later in this guidance.

34 This may include a change, for example, from rural to urban land use.

structures, and the possible use of hard protection structures. In developing and identifying options, there is a need to:

- consider the long-term changing nature of coastal hazard risk exposure
- undertake cost–benefit analysis to compare the outcomes of strategic actions against a 'do nothing' base case
- identify and plan for transition mechanisms and timeframes for taking action.

Policy 27 also expands on the use of hard protection structures, which are specifically discouraged under Policy 25. Through both these policies and through **Policy 26**, there is strong discouragement of hard protection structures, and instead the promotion of the protection and enhancement of natural defences. It is recognised that in some circumstances, however, hard protection structures may be the only practicable means of sustaining regionally or nationally important infrastructure. When considering use of hard protection structures to protect private property, social and environmental costs must be taken into account.

The NZCPS 2010 also directs a strategic approach to use, development and protection in the coastal environment through **policies 6 and 7**. Policy 6 sets out a range of considerations relating to activities (use and development) in the coastal environment. Policy 7 sets out a framework (under the heading of strategic planning) for settlement and for recognising circumstances where subdivision, use and development will be, or may be, inappropriate. As climate change impacts on coastal ecosystems and human systems, as well as coastal physical processes, Policy 7(2), which relates to cumulative threats and significant risks, also has a climate change dimension. This policy requires regional policy statements to identify resources and values at significant risk of adverse cumulative effects and, where practicable, to set thresholds or specific limits at which further activities are to be avoided.

Finally, **Policy 3** requires a precautionary approach towards activities where their effects on the coastal environment are uncertain, unknown or little understood, but are potentially significantly adverse. Coastal resources potentially vulnerable to the effects of climate change are particularly emphasised as requiring a precautionary approach, so that:

- avoidable social and economic loss and harm does not occur
- natural adjustments of the natural environment can occur
- natural character, public access, amenity and other coastal values meet the needs of future generations.

The direction in the NZCPS runs through all planning and decision-making under the RMA.[35] It forms the basis in which adaptation to climate change in the coastal environment can begin to be tackled by communities and their local governments.

[35] Through the requirement that policy statements and regional and district plans must give effect to the NZCPS (RMA sections 62(3), 67(3) and 75(3)), and that decisions on resource consent applications must have regard to the NZCPS as applicable and relevant (RMA section 104).

BOX 4: NATURAL CHARACTER AND NATURAL COASTAL DEFENCES

The importance of natural coastal defences in managing coastal hazards, while also providing for access and habitats for indigenous species, is emphasised in the New Zealand Coastal Policy Statement 2010 (NZCPS 2010) (Department of Conservation, 2010). Natural coastal defences comprise beaches, dunes, estuaries, salt marshes, offshore bars and breaks, islands and vegetation (photographs below show two examples). They are areas where the energy of marine coastal processes – waves, currents and tides – are dispelled, dispersed or dissipated.

The requirement in the NZCPS 2010 that these features are protected and restored as a response to natural hazards, in preference to hard protection structures for coastal protection, recognises their multiple functions (usually helping to maintain natural character, provide natural habitats and enable public access to and along the coast as well as coastal protection) and contribution to the integrity, form, functioning and resilience of the coastal environment. The preamble to the NZCPS 2010 describes loss and degeneration of natural character, open space, habitat and continuing and exacerbating natural hazards as key issues faced by the coastal environment. The direction in the NZCPS 2010 responds to these identified issues.

Relevant references in the NZCPS 2010 are found in objectives 1, 2, 4 and 5, and policies 3, 13, 14, 15, 18, 19, 25, 26 and 27. Local government has a key leadership role in decisions about the types of coastal defences appropriate in any specific circumstance, including the protection, restoration and enhancement of natural defences.

Numerous examples exist of local coast care groups, often working in conjunction with local government, where existing natural coastal defences are being strengthened through restoration, or where the life of hard protection structures is being prolonged through enhanced retention of sediment (Dune Restoration Trust of New Zealand, 2016).

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2.4 Other principles for local government

All local government actions are undertaken in the context of a range of principles that are set out in law or have evolved through good practice and case law. All must be kept in mind when addressing climate change in the coastal environment.

2.4.1 Sustainability and resilience

The concept of sustainable management of an area's natural and physical resources under the RMA and the principle of sustainable development under the Local Government Act 2002 (LGA) support the ongoing ability of communities and people to respond and adapt to change over time in a way that avoids or limits adverse consequences. The purposes and principles in Part 2 of the RMA include a requirement for people making decisions to have particular regard to the effects of climate change.[36] The LGA provides that the avoidance or mitigation of natural hazards is a core local government service, and that particular regard must be had to the contribution this makes to communities in the local government area.[37]

Resilience is a concept closely related to sustainability and is gaining some traction internationally but is not widely enshrined in New Zealand legislation. The LGA requires[38] that, in planning and management for infrastructure, local government must provide for resilience through managing natural hazard risks and by making appropriate financial provisions for such risks. Resilience is, however, a concept that is being widely promoted by local government and communities in relation to natural hazards, taking into account both short- and long-term issues and risks. It is also a core theme in the National Civil Defence Emergency Management Strategy and is referenced in the National Civil Defence Emergency Management Plan.[39]

While the causes of climate change are being tackled at national and international level, local communities are being encouraged to adapt to climate change. These responses fit within the concepts of sustainability and resilience.

The growing understanding of the variability of climate change effects and the range of uncertainties, including in coastal areas, has involved a shift from conventionally applied risk-based assessments of hazard risk to a need to analyse a range of responses to climate change before making decisions on reducing or avoiding risk. This is an adaptive approach, which can accommodate change in the future without locking in investments that make adjustments difficult and costly. This measured approach helps both long-term sustainability and community resilience.

2.4.2 Reasonably foreseeable needs of future generations

The phrase "reasonably foreseeable needs of future generations"[40] means taking into account the interests of future communities and the direct and indirect costs that future generations may bear as a result of decisions made in the present. The concept is found in key sections of the LGA and RMA, and is one of the fundamental considerations in international, national,

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36 RMA section 7(i).

37 LGA section 11A.

38 LGA section 101B(3).

39 The relationship of the various legislative instruments and their local government context is further outlined in appendix A.

40 RMA section 5.

regional and local responses to climate change. The CDEMA refers to the well-being of future generations as a community responsibility.

Even where the need for a response to climate change has not yet been identified, this principle applies. It integrates research and the recognition of trends and associated potential impacts with expectations of future community needs. This principle requires responsible action in the context of balancing present needs with those of the future.

2.4.3 Avoid, remedy or mitigate adverse effects

The duty under section 17 of the RMA, to "avoid, remedy or mitigate adverse effects" on the environment applies:

- in the preparation of RMA plans by local authorities
- to every decision made under that Act
- to everyone who carries out an activity or development.

'Effect' includes temporary or permanent effects, present and future effects, cumulative effects over time, and potential impacts of high probability, or of low probability with high potential effects. An understanding of climate change impacts and trends can and should be taken into account when planning and considering new activities and developments.

Policy 25 of the NZCPS 2010 refers to the risk of "social, environmental and economic harm" from coastal hazards and seeks to reduce, or at least avoid increasing, risks of harm and adverse effects. The implications of specific decisions can best be worked out through a risk-assessment process that considers the realistic permanency of the decision and the anticipated future impacts. Decisions to avoid future effects (such as 'no go' areas for development) will be needed in some situations. In others, mitigation by specific design responses (such as minimum floor levels) may be appropriate. If a future remedy is to be an option (such as relocatable buildings in coastal locations), the implications for present and future owners and the community need to be clearly identified at the time a land-use change or development is approved; and conveyed into the future by reliable mechanisms (such as bonds to cover relocation costs and/or consent notices on titles).

The NZCPS 2010 recognises that adverse effects can arise both from coastal hazards and from some remedies: in particular, the environmental and social costs must be evaluated when considering hard protection structures (Policy 27(1)(d)).

2.4.4 Precautionary principle and the cautious approach

The 'precautionary principle' is implied in the RMA (and set out in Policy 3 of the NZCPS 2010). It is provided for in the CDEMA (section 7). It requires an informed but cautious approach to decisions where full information on effects is not available, particularly when effects are potentially significantly adverse and/or where decisions are effectively irreversible. An example of an effectively irreversible decision is rezoning land from rural to urban use, because of the land fragmentation and the extent of private and public investment that follows.

A precautionary approach is also particularly relevant where effects are of low probability but high potential impact, such as infrequent but devastating storms in eroding coastal locations.[41] In this context, it will be necessary to consider the changing frequency of such events.

[41] Noting that the frequency of such occurrences is increasing due to climate change.

This principle is directly relevant to addressing climate change effects in plans. Section 32 of the RMA requires consideration of the risks of 'acting or not acting' if there is uncertain or inadequate information when developing plan provisions.

It is important to recognise that the principle is applied at the planning response stage (eg, steps 6–8 of the decision cycle) and not the hazard or risk assessment stages (eg, steps 2 and 4).

2.4.5 Ethic of stewardship, prudent stewardship and kaitiakitanga

The LGA and RMA both contain the concept of stewardship. Decisions under the RMA must have regard to stewardship and kaitiakitanga.[42] In the LGA, prudent stewardship is to be applied alongside the efficient and effective use of a community's resources in the interests of the district and/or region. In the RMA, the ethic is applied to the wider environment.

The concepts underpin sound planning decision-making in the interests of the community, to avoid or minimise loss of environmental[43] values or quality over time. Its relevance to climate change is to asset management, land care and water care, biosecurity and biodiversity, but also to land use and development, natural character, amenity and public access values.

2.4.6 Consultation and participation

Principles of engagement with communities[44] and affected people lie at the heart of local government decision-making. Consultation implies informed input into decision-making processes. For decisions with outcomes likely to be influenced by climate change, those being consulted must have enough information to understand the range of scenarios and associated risks for their communities and the increasing risk posed by climate change over time. Ensuring that adequate information is available to a community for consultation to be effective is a responsibility of regional and local government.

Local authorities have different, and clearly specified, consultation responsibilities under the RMA for planning, and the LGA for long-term and annual plans, where community investment and asset management are largely determined. In some circumstances, local government may initiate a special consultative procedure under section 83 of the LGA – to be used where a council seeks to "enable public understanding of the proposal" or where a major decision is involved. Such special procedures may apply to community visioning, strategic planning (see NZCPS 2010, Policy 7) and other pre-RMA planning or LGA engagement, all of which may encompass hazard management in the coastal environment. In the future, making difficult decisions, such as not to maintain coastal roads or sea walls, may require such a procedure.

For climate change, in particular, consultation or engagement involves the translation of international and national knowledge, projections, trends and scenarios to local levels. It also includes indications of degree of certainty and types of uncertainty and the emergence of impacts related to sea-level rise in a risk exposure and vulnerability context. Local government also needs to engage on the basis of developing planning approaches that might address these risks as they increase over time. Ensuring there is balanced and responsible community input into the response options for current and future generations will be an important and ongoing role for local government.

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42 Kaitiakitanga is defined in section 2 of the RMA as follows: "the exercise of guardianship by the tangata whenua of an area in accordance with tikanga Māori in relation to natural and physical resources; and includes the ethic of stewardship".

43 Meaning the broad concept of 'environment' applied under the RMA.

44 Including with iwi, through Treaty of Waitangi principles.

2.4.7 Varying timeframes

Despite the intergenerational nature of both the LGA and RMA, questions frequently arise about planning timeframes.

Other than the responsibility to review RMA policy statements and plans every 10 years, and LGA responsibilities to develop long-term (10-year) and annual plans, legislation has rarely specified planning periods.[45] Practice has, however, developed, and this is beginning to be specified in policy and even legislation. The NZCPS 2010 specifies consideration of "at least 100 years" for climate change related coastal risk assessment. This needs to be the basis for policy and plans, and is subject to review over time in the normal way.[46] Normal urban planning practice would consider land supply over a period of 30 to 40 years.[47] The LGA now requires that local authorities prepare infrastructure strategies for a period of at least 30 consecutive financial years, and include resilience considerations and risk management over that period.

Short to medium timeframes should be able to be addressed in a risk management and forward planning context with reasonable levels of confidence, given that sea-level rise projections are more tightly constrained. In the longer term, however, such as that specified by the NZCPS 2010, there is less certainty which of the range of scenarios will play out. The concept of proportionality can be applied: decisions affecting small areas, few affected people and little sunk investment (excluding cultural, conservation and historic places of value) may reasonably consider climate change implications over a limited timeframe; whereas decisions resulting in large scale and/or permanent change and considerable sunk investment (such as new greenfield areas and major areas of intensified development) must consider the long-term likely impacts of climate change, and also adopt a cautious (precautionary) approach due to greater uncertainty over the longer timeframe about the rate and magnitude of the changes.

2.4.8 Financial responsibility

Local government is expected to act within normal codes of financial responsibility on behalf of the community. In terms of local government activities, particularly asset provision and management, the LGA requires that the reasons for any changes to current provision, and their cost, be identified in detail. Evaluation of financial costs and benefits is now commonplace in local government legislation. Where decisions involve values that are not readily translated into monetary terms (eg, environmental or ecosystems services provided by wetlands or dunes, or loss of cultural values), it is expected other evaluation methodologies, such as multi-criteria analyses, will be applied. There is growing development of new economic analysis tools internationally that can be applied to situations where risk changes over time (see chapter 9).

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45 The exception is the Building Act 2004, where a life of 50 years is specified for core building elements.

46 This was guidance from case law before its enshrinement in the NZCPS 2010.

47 "Up to" 30 years in the just-notified proposed National Policy Statement on Urban Development Capacity 2016.

2.4.9 Disclosure and liability

Local authorities are required to disclose hazard information they have (except where it is apparent from a district plan). For potentially affected properties, they must include on LIMs[48] any information they have about the implications of sea-level rise and coastal processes, indicating levels of certainty associated with the information. This is a requirement under the Local Government Official Information and Meetings Act 1987. It is a responsibility of the council to correctly explain in the notice provided for any site the potential for the occurrence (that is, the reasonable possibility objectively determined[49]) of the hazardous event.

Local government can be financially liable for the consequences of decisions that are shown to have been in breach of statutory or common law duties. This is a difficult area of law, and councils use a range of techniques to reduce their risk of liability. For example, where decisions regarding single properties are involved, instruments such as covenants or consent notices attached to titles may be used to identify risks.[50] It is possible that wider liabilities may arise if, for example, a council zoned an area for new development that was clearly contrary to NZCPS 2010's Objective 5, Policy 7 and Policy 25(a). There may be potential for financial and insurance agencies, as well as individual property owners, to seek recovery of direct costs and lost value. Councils can also use insurance products to insure their own assets and infrastructure for loss – but with an increasing exposure to coastal-hazard risk that affects them, particularly for sea-level rise (see chapter 10).

Broader climate-related issues, such as frequency of inundation of a developed area, may be less likely to result in direct liability unless the area becomes uninhabitable as a result. Community costs in enhancing or retrofitting infrastructure can become considerable, however, and questions of equity in relation to wider community interests also arise.

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48 Land information memorandums.

49 As determined by case law – *Weir v Kāpiti Coast District Council*, High Court, December 2013 (see link to case in appendix B).

50 Care should be taken when using such measures because they may not limit the owner's (or a future owner's) expectations of further capitalisation. Their use does not appear to have any effect on land values. See Harvey and Hawkins, 2008.

BOX 5: RELATIONSHIP BETWEEN THE RESOURCE MANAGEMENT ACT 1991 AND BUILDING ACT 2004

One of the more problematic aspects for territorial local authorities when it comes to managing natural hazards is navigating the relationships between these two key statutes. This is particularly the case when land that is now identified as subject to coastal (or other) hazards has been zoned for urban or similar use and subdivided, and is available for development.

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The RMA can be seen, subject to its varying provisions, as the 'first line of defence' in terms of natural hazards management. Under the RMA, land can be excluded from zoning that would allow development in hazard areas and, even if zoned, 'overlays' identifying hazard areas and restricting development can be applied with an appropriate level of intervention (such as the need for resource consents to be obtained or a requirement to meet specific conditions such as setbacks or floor levels that must be provided in any development). When land is already zoned, its suitability for use and development must be tested again in terms of section 106 of the RMA. This provides councils with powers to prevent subdivision, or to apply restrictive conditions, if there is a significant risk from natural hazards, or if sufficient provision has not been made for legal and physical access. In assessing the risk of natural hazards, section 106(1A) sets out aspects which must be taken into account, including the subsequent use of the land and structures.

If land is zoned, and a proposed building is not restricted under the RMA, the Building Act (BA) has provisions relating to the management of natural hazard exposure. These provisions are, however, focused on the safety of the building and its occupants over the intended life of the building (usually a minimum of 50 years), rather than on the wider environmental consequences of development in a hazardous area. A council can refuse consent for a building if the land is subject to a natural hazard, or if the building work is likely to cause or exacerbate a natural hazard on that land or any other land (BA, section 71). There is no ability, however, to refuse consent if the building consent authority is satisfied that adequate provision is made to protect the land and building work from natural hazards. If specific provisions have been made, these must be noted on the title at the time the consent is issued, so insurers, banks and future owners are aware of the presence of the hazard. Natural hazards include coastal erosion and inundation from tides and storm surge. The associated building regulations have no explicit requirements to consider the effects of climate change on inundation hazards, including increasing risks over time.

The tension between the two Acts and, in particular, the difficulty territorial authorities have in refusing to grant building consents in areas that may become subject to coastal hazards over the next century, particularly surfaces when RMA provisions relating to the site do not provide appropriate controls over protection structures such as sea walls and retaining walls on sites. On-site protection may be accepted under the BA in a way that is inconsistent with the NZCPS 2010. A further tension arises due to the different timeframes of the two Acts, with the BA providing for decisions that may be seen as inconsistent with the longer-term focus of the RMA. This tension means local authorities and their communities need to recognise the importance of the RMA in managing natural hazards through planning processes.

BOX 5: RELATIONSHIP BETWEEN THE RESOURCE MANAGEMENT ACT 1991 AND BUILDING ACT 2004

A particular problem for the future and for adaptive planning is the extent to which coastal communities choose to rely on the existing hard protection structures protecting urban areas from natural coastal hazards, or new ones that may be sought by the community in future. Such 'public' natural hazard protection may provide the certainty that the BA requires for the lifetime of new buildings (usually the next 50 years), but their effectiveness to protect investments in the long term is uncertain. This raises issues in terms of the management of density and intensification of development in coastal areas, which again is a matter to be addressed under the RMA.

More detail on the two Acts, and the relationships between them, is provided in appendix A.

2.5 Adapting to climate change and adaptive pathways

Planning and decision-making in a context of uncertainty is not new. The concepts of managed risk, and no- and low-regrets decisions, are familiar to local authorities. Evaluating alternative approaches or methods in infrastructure and land-use planning has long been a requirement of local government. What makes the current decision framework more complex in the context of climate change and sea-level rise is its scale, the need to understand and integrate multiple considerations, and the potential consequences, including individual and community costs of inaction or 'getting it wrong'.

Decisions that are not carefully made on the basis of the best knowledge may incur significant costs due to:

- lack of recognition of risks and consequences (providing for development in areas that either need expensive protection or must be removed during the economic life of the investment)
- incorporating remediation or mitigation prematurely at unnecessary cost.

This can include investments in publically owned infrastructure where the economic potential is curtailed. The consequences of such decisions can persist well into the future and may also compound risk.

To help local government and communities with more significant decisions, where the magnitude and rate of sea-level rise is uncertain, concepts of decision-making along 'adaptive pathways' are now being used internationally to plan for adaptation over time to anticipate how the future actually unfolds. The approach is based on the premise that policies and decisions will eventually fail to meet objectives and need to be revisited and adjusted or replaced as the operating conditions change (Kwadijk et al, 2010). Once a decision or action reaches a stage where it fails to meet objectives, additional decisions or other actions may be needed to achieve the objectives. The process can be seen as a series of interlinked pathways to meet objectives and the conditions under which they fail to meet them (adaptation threshold) with associated triggers, and will be tested against scenarios of the future. At predetermined trigger (decision points), a change in course can be implemented to continue to achieve the objectives. By exploring different pathways for their ability to meet objectives, an adaptive plan can include short-term actions and long-term options. The plan is monitored for signals and then triggers that indicate when the next step of a pathway should be implemented, or whether reassessment of the objectives or the plan as a whole is needed.

Risk and uncertainty considerations are transparent in the scenarios and story lines used in such planning. Scenarios are not predictions of what the future will be; they are a description of how the future might unfold. They can help inform the development of objectives and policies, including the objectives that help inform risk management. Scenario and storyline development is also an effective way of engaging with communities to help identify actions that will contribute toward acceptable futures and help avoid unacceptable futures. Communities can help decision-makers to make decisions in a timely manner by contributing to the identification of signals and triggers (decision points), and the circumstances in which a further decision will be needed.

Adaptive pathways have long timeframes, which transcend normal local government and RMA cycles. The pathways can be embedded in policy at regional or district level, however, and/or in regional and district plans and passed on into future plans through review processes if still relevant. The RMA and NZCPS 2010 already require that local authorities take a long-term view in planning, so the concept is not new or unusual. Furthermore, planning processes have long required ongoing monitoring and evaluation of the effectiveness of implementation efforts and, where appropriate, revising or adapting plans so their underlying objectives can be achieved in the face of a changing and uncertain future.

Figure 1 is a simple illustration of the long-term integrated planning and decision-making framework in which local government and communities can manage coastal hazard risk and climate change adaptation. As can be seen from this 10-step decision cycle, the process is essentially cyclic, with opportunities for revision processes over time. New information, the findings of monitoring, or social, economic or cultural change may initiate review and changes in management over time.

An adaptive management approach to coastal change is possible in current legislation and practice, but at present there are few examples. The example of Mapua and Ruby Bay (box 6) provides a case study of current good practice, retaining options for future decision-making in terms of an area identified as at high risk for adverse effects of coastal processes, including the effects of climate change.

BOX 6: CURRENT GOOD PRACTICE: MAPUA AND RUBY BAY (PLAN CHANGE 22, TASMAN DISTRICT COUNCIL)

Detailed planning for the small coastal communities of Mapua and Ruby Bay began in the late 1990s. It was undertaken in an environment of considerable pressure for coastal development across the whole of the Tasman coastal area, from Richmond to Motueka, including in the settlements themselves. The approach to plan preparation was an integrated one, identifying and addressing the multiple challenges faced by the two communities, which ranged from natural hazards issues to management of a major contaminated site, and appropriate provision for residential and business land and associated servicing.

The plan evolved over more than a decade, involving an initial stage of information collection and analysis and a structure planning process. Key elements were the intention to provide for future expansion "away from low-lying land and the inundation and erosion-prone coastline between Mapua and Ruby Bay". It involved revising the pre-existing coastal hazard area to take into account coastal erosion, coastal and freshwater inundation, climate change and sea-level rise, and activities that could increase risk. Further subdivision on the coastal plain and sand spit areas was to be prevented, and erection of new buildings in identified hazard areas was also to be avoided, to avoid the long-term adverse effects of coastal erosion and inundation.

With a clearly expressed policy framework, elements of the plan included the identification of a Residential Closed Zone (further subdivision prohibited, no land filling, no new habitable buildings and no extension or replacement of existing habitable buildings closer to the shore) based on the then-current national guidance for sea-level rise and climate change effects. Coastal protection structures became restricted discretionary activities, with effects on the natural environment, adjoining properties and coastal processes being considered.

The plan went through several stages of engagement and a draft statutory plan process, allowing for detailed comments on policy and regulatory components. The formal processes of Plan Change 22 proceeded with wide public interest and debate, submissions, and a council hearing and decisions. The council had successfully sought a declaration from the Environment Court that the subdivision rules should have immediate effect, which the court granted on the basis of the circumstances (see link to case in appendix B). Part of the area was subject to appeal to the Environment Court in 2014 (ENV 2012 WLG 000052), which was rejected in favour of Tasman District Council. From the evidence at the hearing, it became apparent that the council has made no decision on whether the major rock revetment at Ruby Bay (photo below, right panel) will be retained in the long term.

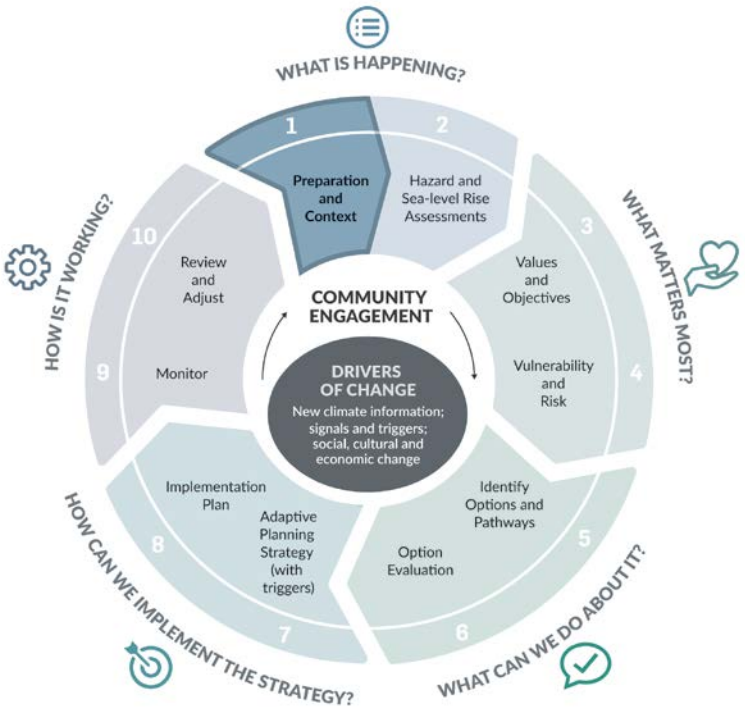
This is an example of planning that is current good practice for coastal hazards and that has retained options for future decision-making. In the meantime, the robustness of the provisions have been subject to testing through the Environment Court. The council is monitoring the wider plan as well as the continuing coastal processes.

Photo credits: (left) Mapua foreshore; (right) Ruby Bay rock revetment after a wave-overtopping event (both E Verstappen, Tasman District Council).

3 Community engagement principles

Chapter 3	**Chapter 3 covers:** • what is meant by 'community' • rationale for engaging with the community, iwi/hapū and stakeholders • use of the International Association for Public Participation spectrum of public participation to align terminology and support thinking on engagement practice • guiding principles to underpin the engagement process • overview of engagement methods and tools, with links to other resources • how to navigate the engagement components of this guidance.
Step 1	**Key tasks** a. Identify who to engage with (stakeholder analysis). b. Understand and document the current social context. c. Decide how the community will be represented in the engagement process. d. Decide what level of engagement is needed. e. Formulate an engagement process underpinned by guiding principles that can be extended through the various steps of the decision cycle.

Figure 5: Step 1 in the 10-step decision cycle: What is happening? – preparation and context



In this guidance, the term 'engagement' is used to describe an interaction or series of interactions between decision-makers, local government and the community, iwi/hapū and stakeholders. It may be a single event or activity, but is more often a process comprising a sequence of activities and events that combine and build towards making a decision.

This chapter provides background material supporting community engagement for coastal hazards climate change adaptation. This material also supports engagement-related components in other steps in the decision cycle later in the guidance.

3.1 What is a community or stakeholder?

The terms 'community' and 'stakeholder' overlap, and there are also local, regional, national and international elements, as shown in figure 6.

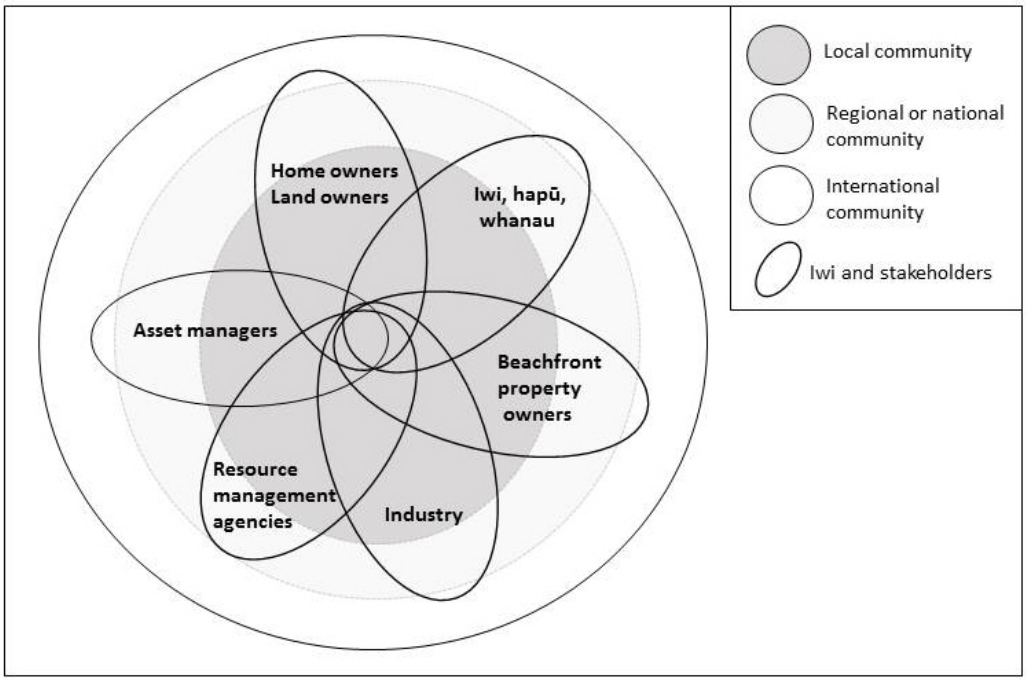
The local community consists of those who live in a particular location, while stakeholders are those with an interest in the geographic area (specifically in something of value or importance, and that is at stake).

Iwi, hapū and whānau have partnership status through the Treaty of Waitangi, and may live in the local community or further away.

Stakeholders will include beachfront and other property owners, home owners, land owners (eg, farmers), industries, business owners and resource management agencies.

It is also possible to have several interests or stakes in an area, or to live in a community and not own property or a business. All these groups have a strong connection with the local area. Future generations are considered stakeholders because they will inherit the current decisions on coastal hazard management or adaptation. The voice of future generations is represented by local government or, in some cases iwi/hapū and non-governmental organisations. The term 'communities, iwi/hapū and stakeholders' is intended to be inclusive, describing the groups of people who should be included in adaptation decisions.

Figure 6: Overlap in definitions of community and stakeholders



Note: Iwi and hapū have partnership status. The stakeholders list is not exhaustive, nor does it imply importance.

3.2 Why engage with the community?

Adaptation to ongoing sea-level rise (SLR) will require individuals, families, communities, businesses, infrastructure and utility providers, local and central government to make choices about the future. Each decision will require careful consideration because:

- the rate and magnitude of SLR is uncertain, especially later this century and beyond. It is contingent on several factors, including collective global response to mitigation of greenhouse gas emissions. In addition, hazard risk profiles will exhibit a wider range of possible future impacts (see chapters 5 and 6)
- a wide spectrum of stakeholder, community and iwi/hapū and whānau interests and expectations exist. Key groups include iwi/hapū (as Treaty of Waitangi partners), coastal property owners, the wider local community, industries, community special interest groups and local government (which provides services and manages resources for future generations)
- disagreement of values and world views exists, which may result in a lack of consensus over future actions and outcomes
- impacts of SLR and associated adaptation options will not be distributed evenly across society, trade-offs are likely to occur and some groups in society will be disproportionally affected (Local Government New Zealand, 2016b)
- some decisions may be irreversible and create 'lock-in' that fixes the direction of future decision-making. This may reduce future adaptive capacity and eventually require more costly responses (Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), Denton et al, 2014).

Decisions regarding adaptation to SLR need to be, and must be, made. But how can this occur in a way that recognises the factors above, as well as the many different decisions occurring at different scales, each requiring choices on the level of public engagement and participation?

It is widely accepted that engagement with local communities, iwi/hapū and stakeholders will be essential because they (and future generations) will be affected by coastal hazards and change, and their lives and values are likely to be affected (Ford et al, 2016; Sheppard et al, 2011). As a consequence, it is generally accepted that they should have a role to play in decision-making regarding future adaptation.

Several additional benefits are likely to result from more inclusive decision-making.

- More robust definition of problems can occur. Exploring what is valued and how those values and associated practices affect other stakeholders, including ecosystems and future generations (Cote and Nightingale, 2012), can provide a context that favours understanding, coordination, cooperation and compromise (Davies et al, 2015).
- A wider range of planning and decision-making alternatives can be created, explored and assessed.
- Certainty of policy outcome is likely to reduce the risk of policy implementation failures (Videira et al, 2011) and unintended consequences.
- Better and more robust decision-making is likely (Berkes et al, 1998; Olsson et al, 2006; Stringer et al, 2006), which is more suited to the dynamic risk of SLR (ie, risk and exposure to harm or damage increases over time, but with less certainty in the longer term).
- Engaging stakeholders early and throughout the process is likely to improve efficiency, save time, reduce litigation costs and, through development of a shared understanding of social values and interests (Pahl-Wostl and Hare, 2004), can help reach decisions that can be implemented (Voinov and Bousquet, 2010).

- Working with communities creates opportunities to improve the understanding of climate change impacts and potential responses (Wiseman et al, 2010).
- Trust in government (central and local) is more likely to be retained or improved.

It is difficult for iwi/hapū, communities and stakeholders to prepare themselves for, and to respond to, situations where the risk profile is changing unpredictably in the future. Overall, discussion and debate are likely to lead to a greater shared understanding of the:

- causes of the problem
- problem itself
- risks and vulnerabilities
- values at stake
- range of responses possible.

Identifying what is possible and the development of an implementation plan are likely outcomes.

3.2.1 Who should participate?

Establishing who should participate is a critical step, which must be completed with care because withholding participation can be perceived as a strategy to regain and/or retain power and influence (Hayward et al, 2004; Lebel et al, 2006), and favour particular outcomes. If participants are identified and inclusion is done well, it can achieve long-term support, viability and legitimacy of the process (Reed et al, 2009).

The first step in deciding who should participate is to identify the spatial boundaries and who has an interest within those. This will include iwi/hapū, the community, and stakeholders at the national, regional or local level.

It is recommended that participation should be more rather than less inclusive, because including a wide set of values from the beginning will help generate community, iwi/hapū and stakeholder support for the development and implementation of a plan. Several stakeholder analysis tools and methods are available to support the engagement process. They are generally underpinned by a number of key questions (table 1).

Stakeholder identification can be an iterative process, where conversations with one group highlight additional participants (Reed et al, 2009).

Table 1: Questions underpinning the different methods used to identify stakeholders

Key questions	Supporting questions
What are the boundaries for this engagement process?	Is it defined geographically? Is it defined by coastal physical processes, eg, wider sediment budget sources or sinks? Is it defined by the purpose? Is it defined by those who have an interest in the area? What are the wider (regional or national) interests affected by decisions at the coast?
Who are the local iwi/hapū representatives?	Who should be engaged with? What existing relationships exist, and with whom? Are there established protocols for engagement or key contacts? What documents already exist, eg, iwi management plans? What are the jointly agreed mechanisms for inclusion? Will a separate parallel process for iwi/hapū, or a combined process, be applied?

Key questions	Supporting questions
Who forms part of this community?	What social data is available on the community? Who is here? What demographic data is available?
Who is currently affected or could be potentially affected?	Who owns the property in potentially at-risk areas? Who could be affected by adaptation decisions? Who has assets, utilities or interests in the area?
Who are the key local community groups or community representatives?	What networks and relationships can be used to identify existing groups? Who do they represent? What are their interests?
Who are the key representatives from other agencies and sectors?	What other central or local government agencies should be included? What other sectors have an interest or assets that could potentially be affected?
Who is not represented by the existing groups?	What mechanisms exist to facilitate their inclusion? How could they be reached and by whom?
How can the values without a voice be considered?	How can future generation's interests be considered? Who is representing valued ecosystems? How can ecosystems or species values be considered, eg, salt marsh, dotterel habitat?

3.2.2 Understanding current social context

Along with a stakeholder analysis, information should be collated and interpreted to provide an overview of what is already known about the community, iwi/hapū and stakeholders (table 2). Analysis of this information will provide good baseline information to inform and support the engagement process.

Table 2: Questions underpinning different methods to understand the current social context

Key questions	Examples of supporting questions
What non-climate change related pressures and issues does this community face?	What challenges does the community face? Social (equity, deprivation index, ratio of holiday homes to permanent residents) Economic (employment, number and size of local businesses) Cultural (iwi/hapū pre- or post-settlement, resources and capacity)
What information already exists on values aspirations?	What is contained in iwi management plans? What is contained in community outcome documents and community board reports? Survey data? What other historical data exists?
What are the historical experiences of coastal hazard and climate change impacts?	Who has been impacted? How have they been impacted? How often?
What are the existing levels of conflict, debate or agreement around coastal climate change adaptation?	What is the history of the adaptation discussion? What is the range of views and perspectives? Do different groups have preferred options? What are the differences and similarities in views?

3.2.3 How should participation proceed?

How participation occurs will be different at various points in the process and should be designed to suit the local context and the stage and scale of the decision process.

Three ways of working with iwi/hapū and the community and stakeholders have been identified (table 3); each has advantages and disadvantages. Each approach is revisited in the following chapters, for steps in the decision cycle where community, iwi/hapū and stakeholder engagement is needed.

Table 3: Facilitating community and stakeholder inclusion in the decision-making process

Type of participation and description
Whole of community inclusion – as far as possible, the whole community is included in the engagement. **Advantages:** All voices are heard, very effective at a small local scale, with communities that are closely linked together or where autonomous actions are required. **Disadvantages:** Challenging at a large spatial scale, time consuming.
Sub-groups of representatives are formed to represent community, iwi/hapū and other stakeholder groups. **Advantages:** Works at a large spatial scale and is representative of local interests. **Disadvantages:** Relies on the representative to interact with the group that selected them (feedback and canvassing of views). a) Bottom-up selection The community, iwi/hapū and stakeholders select a sub-group to represent their interests or someone volunteers. **Advantages:** The community can select the representative who they feel best represents their interests, this person will be known and trusted. **Disadvantages:** The representative could lack experience in decision-making in a hazards planning and policy setting. A volunteer may not have the mandate from others. b) Top-down selection The local authority invites the representative who it feels has the appropriate skill set and legitimacy to represent local interests. **Advantages:** The representative will have a knowledge of, and experience with, decision-making in a hazards planning and policy setting. **Disadvantages:** The selected representative may lack community mandate and be unable to make connections within the wider community.

Each option must be weighted carefully in the particular decision-making context, and for the particular purpose of the engagement.[51]

Iwi and hapū should be included in a way that reflects Treaty of Waitangi partnership and in line with how local iwi/hapū, whānau and Māori business wish to be engaged with. This may be different from location to location, because each area or region will have different structures and organisations representing iwi/hapū and whānau. Relationships should already be well established as part of the ongoing interaction between individual local government agencies and iwi/hapū for other resource management activities (eg, water management, Local Government Act 2002 (LGA) and Resource Management Act 1991 (RMA) processes). New relationships will likely be needed, consequently a person(s) who is able to guide and strengthen relationships and facilitate the inclusion of iwi/hapū is an essential member of the adaptation team (see chapter 1).

[51] Further discussion on these choices can be found at https://www.landcareresearch.co.nz/__data/assets/pdf_file/0018/74430/Setting_Collaborative_Process_Stakeholder_Participation.pdf.

Lessons on iwi and hapū engagement can be drawn from experiences in freshwater management (Harmsworth, 2005; Harmsworth et al, 2015).

Once the structure of who is involved has been decided, the mandate of each participant should be determined. Are they there to represent a group, or as an individual? Do they have the right to make decisions on behalf of the group (Bryson et al, 2013)?

3.3 Spectrum of public participation – where to position the engagement

Many terms are applied to community, iwi/hapū and stakeholder engagement, which can create confusion and misunderstanding. The International Association for Public Participation (IAP[2]) spectrum of public participation (figure 7) is helpful for several reasons.

- It provides clear descriptions of what each type of public engagement could entail and how decisions could be made. These approaches can be directly linked to methods.
- The spectrum can be applied at two levels:
    1. at the whole engagement process level, for example, how to go about making a decision regarding coastal adaptation in a particular place. Will a process built around informing, consultation or collaboration be the most appropriate?
    2. how best to undertake a particular event or activity as part of a larger process. For example, is this activity about sharing information with a wide audience or understanding local values?

Adopting a uniform and generally accepted terminology will help align expectations and practice.

Figure 7: The International Association for Public Participation spectrum of public participation

INCREASING IMPACT ON THE DECISION

	INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
PUBLIC PARTICIPATION GOAL	To provide the public with balanced and objective information to assist them in understanding the problem, alternatives, opportunities and/or solutions.	To obtain public feedback on analysis, alternatives and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.	To place final decision making in the hands of the public.
PROMISE TO THE PUBLIC	We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision. We will seek your feedback on drafts and proposals.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will work together with you to formulate solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.

Source: International Association of Public Participation (2014) – with permission

Four critical, inter-related questions should be considered when determining whether informing, consultation, involvement, collaboration or empowerment should occur. These questions can be applied to the entire engagement process or to individual activities or events in an overall process.

- What is the nature of the decision?
- What is the purpose or goal of the engagement?
- How heterogeneous are the community, iwi/hapū and stakeholder values?
- How are the potential impacts distributed?

Responses to these questions have implications for the scale of the engagement and which activities should occur.

3.3.1 What is the nature of the decision

The type of decision being addressed influences the likely process of engagement. If the decision is associated with a consent or subdivision application (eg, new infrastructure or redevelopment, such as intensification) or greenfield development, then the consultation process is clearly articulated in good practice associated with both the application of the RMA and LGA, and should be underpinned by the hazard, and risk and vulnerability assessments and

approaches in this guidance. In practice, the statutory process sits between 'consult' and 'involve' on the IAP^2 spectrum (figure 7). If the decision is on how to influence individual behaviours, hazards policy development or local adaptation, then a modification of the statutory process can be constructed based on the remaining critical questions.

3.3.2 What is the goal or purpose of the engagement?

Engagement can serve several purposes, ranging from providing information and stimulating debate to making and implementing local adaptation decisions. Each of these purposes needs to be approached differently.

Where the purpose is to provide information (for example, the Waikato Regional Council coastal inundation tool[52]) to support individual stakeholder decision-making, or to increase public awareness or knowledge of a particular issue, then informing the public is an appropriate choice. The process of informing will typically follow science communication methods (box 7), social marketing techniques and social media. These processes can occur at a national, regional or district scale, and are most effective when the science is accepted, the problem is simple and the level of trust in the source of the knowledge is high.

BOX 7: NEW ZEALAND GUIDANCE ON SCIENCE COMMUNICATION

There cannot be a scientifically engaged public without a publicly involved science sector.

The Royal Society of New Zealand has developed guidance for researchers on communicating science: *Public engagement guidelines for researchers, scholars and scientists*. These guidelines seek to foster and support effective engagement between researchers and society. The guidelines are based on three principles: a) that society benefits from being engaged and informed about new knowledge and its application; b) that differing contexts of engagement bring different obligations; and c) that acting with professionalism and transparency are necessary to build and maintain public trust.

Source: www.royalsociety.org.nz/research-practice/public-engagement-guidelines

It is important to note that, although providing information to increase knowledge and awareness is a necessary element in all engagement processes, for approaches further along the IAP^2 spectrum (figure 7), it occurs as one of several integrated and iterative steps rather than as a single step.

If the purpose of engagement is to make a collective decision (eg, local hazards policy or adaptation alternatives), then increased community, iwi/hapū and stakeholder involvement will be needed.

Table 4, 5 and 6 provide further questions that may be considered to identify the position along the spectrum of participation that is appropriate (table 4). The answer to each question will place the engagement in either the 'inform or consult', 'involve or consult' or 'collaborate or empower' section. Once all the questions have been considered, the balance of responses will sit in one of the columns. This will indicate which position along the IAP^2 spectrum would best suit the situation being considered.

52 See www.waikatoregion.govt.nz/coastal-inundation-tool/.

Table 4: Key questions when exploring the type of engagement process to undertake – based on purpose, knowledge and complexity

Questions	Inform or consult	Involve or consult	Collaborate or empower
Agreement on the science: To what degree do all the participants agree on the science and knowledge required to solve the problem?	It is a **simple problem**, with direct and agreed links between cause and effect. The **science is undisputed** both by technical experts and others.	It is a moderately complex problem with **some level of disagreement** between both technical experts and others over the science of the problem. **Some of the science is unknown.**	It is complex problem with **high levels of disagreement** between both technical experts and others over the science of the problem. **Scientific knowledge has gaps and uncertainties.**
Complexity of the problem: How difficult is it for all participants to gain an understanding of the problem, and how much time and effort will it take to acquire this knowledge?	The problem is **simple** and easy to learn about. Understanding the problem is not time consuming or difficult.	The problem is **moderately difficult** to understand and will take some time to learn about.	The problem will take time and effort to understand, and is **challenging to grasp** due to its complexity.
Levels of trust: To what degree do all the participants trust the current governance arrangement to protect or manage their interests, or implement a change?	**High** levels of trust.	**Moderate** levels of trust.	**Low** levels of trust.

Others = communities, iwi/hapū and stakeholders. Compiled from Hurlbert and Gupta, 2015.

As indicated, the more complex and contested the decision(s), the greater the level of recommended community or public inclusion.

3.3.3 How heterogeneous are the community, iwi/hapū and stakeholder values?

The diversity and alignment of stakeholder, iwi/hapū and community values and norms and the existing level of trust between social groups has a substantial influence on where along the spectrum of participation to position a public engagement process (table 5). In general, less contentious issues can be managed through a process based on informing (figure 7). Where the values are diverse, creating a forum to expose and explore the differences will be necessary.

Table 5: Key questions when exploring the type of engagement process to undertake – based on values and trust

Questions	Inform or consult	Involve or consult	Collaborate or empower
Agreement on values and norms: To what degree do all the community, iwi/hapū and stakeholders have similar values and norms?	A **high level** of agreement regarding values and norms, there is **virtually no conflict** over what should be done.	A **moderate level** of agreement regarding values and norms, there is **some conflict** over what should be done.	A **low level** of agreement regarding values and norms, there is **significant conflict** over what should be done.
Levels of trust: To what degree do all the participants trust the other participants?	**High** levels of trust.	**Moderate** levels of trust.	**Low** levels of trust.

Compiled from Hurlbert and Gupta, 2015.

Accounting for a range of views and values is an essential aspect of transparent, democratic management and governance in the 21st century (Kasemir et al, 2003).

Who to include in the process and how to gain an understanding of values and the degree of conflict or differences will be covered in more detail in chapter 7 (step 3 of the guidance process diagram – defining values and objectives).

3.3.4 How are the potential impacts distributed?

In addition to the increasing impacts of coastal hazards and SLR on communities, iwi/hapū and stakeholders, the distribution of impacts needs to be considered (table 6). Some groups in society will be disproportionally affected or will need to change their behaviour, livelihoods or properties more than others. Where the impacts are high and the need to adapt is high, more inclusive approaches will be required. Similarly, at locations currently experiencing impacts, or where impacts are likely to be experienced within the next decade, a highly inclusive approach should be implemented. At locations where impacts are more distant, they may be approached initially through the statutory planning process and careful location of new infrastructure. In future, however, more detailed adaptation plans may be required.

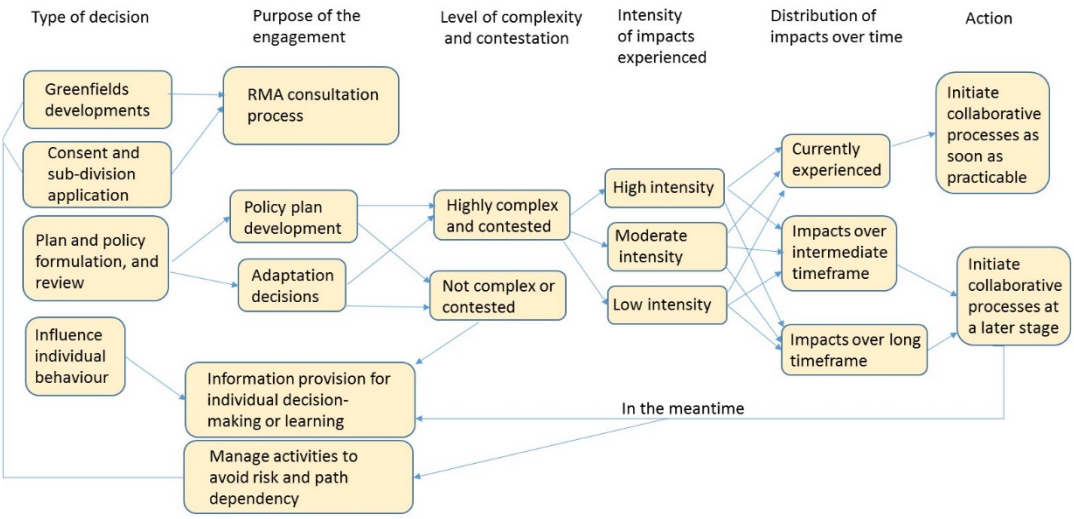
Table 6: Key questions when exploring the engagement process to undertake – based on impacts and distribution

Questions	Inform or consult	Involve or consult	Collaborate or empower
Impacts: How will communities, iwi/hapū and stakeholders be affected by this problem and its potential solutions?	**Minimal** impact.	**Moderate** impact.	**High** impact.
Timing of the impacts: Over what timeframe will the impacts be experienced?	Impacts will be experienced over a **longer timeframe** (potentially 50 years).	Impacts will be experienced over an **intermediate timeframe** (potentially 20 years).	Impacts are **experienced now** or will be **experienced in the next decade**.
Levels of behavioural change required: How much will individuals and groups in society have to change their behaviour to solve this issue?	**Small** behavioural change may be required – these will be simple to achieve.	**Some** behavioural change required, although it is not substantial or disruptive.	**Large** behavioural change required, in some cases transformational change is necessary. Has the potential to cause considerable disruption to some parts of society.

Compiled from Hurlbert and Gupta, 2015.

It is likely that most community, iwi/hapū and stakeholder engagement processes focused on adaptation to coastal climate change will be best underpinned by a high degree of participation (towards the right of the IAP[2] spectrum of public participation, eg, collaboration). The rationale is that, where complexity, risk and differing opinions and values are likely to be great, more intensive participatory processes that include sharing technical information and involvement in analysis and decision-making will lead to more effective long-term solutions (Pahl-Wostl and Hare, 2004). Figure 8 shows the relationship between the four key questions and types of engagement process. It can be used as a visual guide to complement the preceding tables.

Figure 8: Relationship between the key questions and type of engagement that should be undertaken



Note: RMA = Resource Management Act 1991.

For example, at Muriwai Beach (see appendix I), the council needed to make planning decisions regarding long-term adaptation to coastal erosion. The beach was highly valued by a range of iwi/hapū, community members and stakeholders, so the situation was highly complex and the solutions were contested. As high-intensity impacts of coastal erosion were already being experienced, the council instigated a collaborative process to consider the options and design an implementation plan. Where communities are already experiencing the impacts of sea-level rise, a collaborative process should be established as soon as practicable. In places where the effects are more distant in time, a collaborative process can be postponed to allow more urgent situations in other places to be resolved. In the meantime, however, processes could be established that include informing the community and managing activities to avoid risk and creating path dependencies.

3.4 Guiding principles for inclusive engagement processes

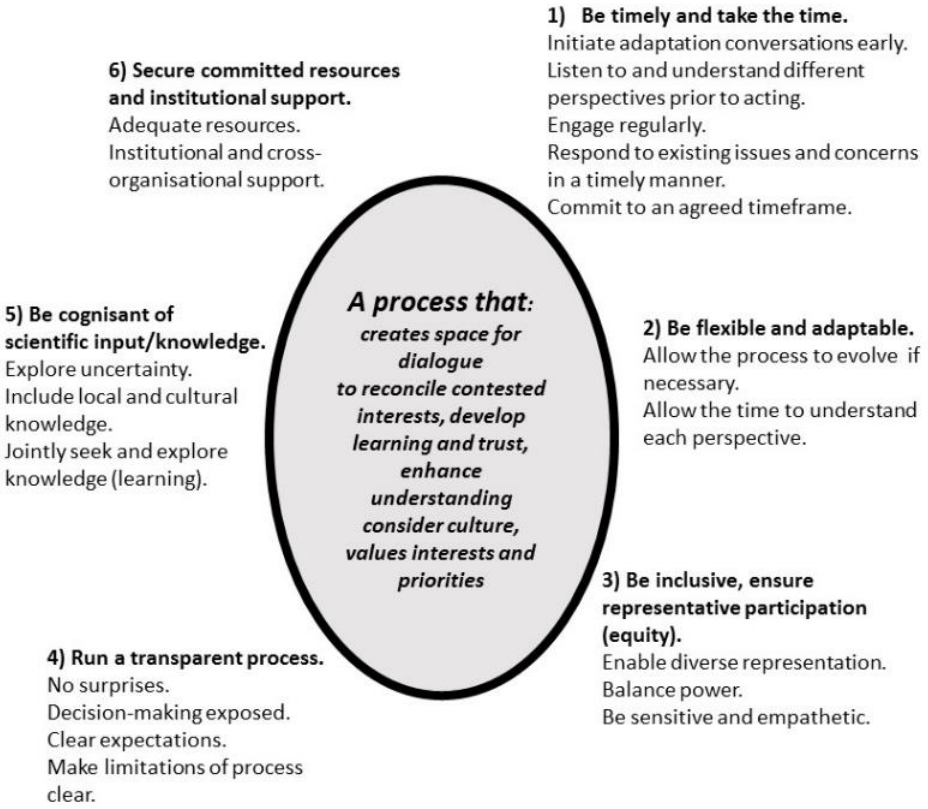
As most decisions made on adaptation to sea-level rise are likely to require an engagement process that falls towards the consultation and collaborative end of the engagement spectrum, the next question is "how to establish such processes to give them the best chance at success?" Perhaps the most important role for any organisation or individual involved in any community engagement process is to create and maintain a safe space where dialogue, deliberation and negotiation may take place (Rouse et al, 2016; Schneider, 2014). This will create a space where participants have the opportunity to build understanding and knowledge with consideration of culture, values, interests and priorities, critically examine existing policies

and plans and proposed solutions in order to reconcile contested interests, develop learning and trust, enhance understanding (Rouse et al, 2016).

This engagement space must also be strongly grounded in local communities where the impacts are likely to be felt, allowing the engagement process to be tailored specifically to suit the local context and societal structures, making linkages to nationally based agencies where relevant (eg, asset and utility agencies and funding bodies). No single recipe for community engagement exists.

Common lessons from participatory practice have been grouped into six principles that provide a framework, or way of thinking, for community engagement (figure 9). These principles define the space for dialogue and can be applied at various scales with multiple parties. They can also provide a reference point to guide the design of engagement processes and a benchmark against which practitioners and communities can evaluate the process as it occurs (Bryson et al, 2013).

Figure 9: Principles that encourage effective dialogue



Following these principles will help design a process that:

- allows for dialogue
- allows reconciling of contested interests
- develops learning and trust
- enhances understanding
- considers culture, values, interests and priorities.

Each guiding principle provides a building block that will lead to achieving this goal. The principles are not mutually exclusive, and none is more important than another. All six principles interact in complex ways to contribute to an engagement process.

Guiding principle 1: Be timely and take the necessary time

Community engagement is often compressed into short timeframes to manage cost (Irvin and Stansbury, 2004; Muro and Jeffrey, 2008). Genuine dialogue and debate requires time to build relationships, understanding and trust. General guidelines often associated with successful participatory processes include the following.

1 ***Recognise that sea-level rise presents an ongoing challenge and that conversations should similarly be ongoing.*** Adaptation to sea-level rise will require ongoing dialogue due to the long timeframes and changing nature of the risk, so building strong relationships that encourage ongoing conversation is critical.

2 ***Initiate adaptation conversations early.*** Dialogue around the potential impacts and implications of sea-level rise, changing risks and adaptation options should occur well before any decisions are made or impacts felt. This allows real dialogue to take place, where perspectives may be shared constructively. Once impacts begin to be felt (ie, coastal erosion event or permanent inundation), the pressure to act will increase (Blackett et al, 2010a; Reisinger et al, 2014).

3 ***Listen to and understand different perspectives before acting.*** Multiple individuals and groups in a community are likely to be affected by sea-level rise, and each will bring a different set of values, perspectives and desired outcomes. Successful processes allow time to hear and understand each one. Furthermore, it takes time to build trust between all parties, especially if historical relationships are poor or absent (Lebel et al, 2006).

4 ***Engage regularly*** to maintain momentum and ensure input to all stages, including objective setting, assessment and evaluation of options, implementation planning and monitoring.

5 ***Commit to an agreed timeframe.*** There will always be pressure to speed up the process to "get on with the job" or "manage costs", or slow it down "because we don't need to do anything yet".

6 ***Respond to community concerns in a timely manner.*** Direct communication with concerned community members will build enduring and positive relationships that will help to achieve the group's objectives.

Guiding principle 2: Be flexible and adaptable

Adaptive approaches will be needed to address the complexity of the changing risks associated with coastal hazards and SLR (Folke et al, 2005; Reisinger et al, 2014). Once a process has been developed, it should retain the ability to evolve to meet the changing needs of the participants or a shift in context – for example, if new knowledge is required on a previously unrecognised impact, such as a shift in risk (sea-level rise accelerates) or a change in government policy. Flexibility will help ensure the process remains relevant.

Guiding principle 3: Be inclusive, empathetic and ensure representative participation (equity)

How this principle is effected will influence who gets to participate in decision-making and who benefits or loses from the outcomes associated with participation. The representation of diverse interests, including future generations and others who cannot represent themselves (such as ecosystems), is an important element to include when designing a process (Cote and Nightingale, 2012).

Vulnerable or marginalised individuals and communities are usually under-represented in decision-making and disproportionally affected (Ford et al, 2016). Some groups in society are

likely to be more adversely affected by sea-level rise and adaptation strategies than others. Conversely, some participants have greater influence and ability to pursue their particular interests than others, which can be to the detriment of those who are less influential (Glavovic, 2015). Providing a voice for all participants increases the likelihood that the participatory process will be perceived as fair and legitimate (Blackett et al, 2010a; Tippett et al, 2007). Considering multiple values and preferences builds the legitimacy of decisions. It also allows the timing and scale of impacts, which could occur over several generations, to be addressed more effectively in the present through adaptive approaches.

The final, but significant element, is to establish a process that is sensitive and empathetic, because for many participants a lot is at stake (eg, private property and valued aspects of the environment) and decisions may have far-reaching consequences (Parliamentary Commissioner for the Environment, 2015).

Guiding principle 4: Run a transparent process

In essence, this guiding principle aims to provide clarity regarding:

- who is involved
- how they are involved
- why they are involved
- how the process will proceed
- how decisions will be made
- identifying the limitations and opportunities for making joint decisions.

All participants must have clear expectations of the process (Gray, 2016) and where responsibility for decision-making lies. Transparency is critical to enabling communication and trust building among a diverse group of participants and decision-makers (Brown Gaddis et al, 2010; Korfmacher, 2001; McNie, 2007; Parliamentary Commissioner for the Environment, 2015).

Guiding principle 5: Be cognisant of scientific input and knowledge

Other chapters set out the key characteristics of coastal hazards and sea-level rise, in particular explaining that, while sea-level rise trends in the short term are reasonably certain and understood, the rate of change and its magnitude over longer timeframes is less certain and unpredictable. Consequently, decision-makers should seek adaptable solutions that are robust in multiple possible futures. Communities, iwi/hapū and stakeholders should be supported to consider multiple possible futures and high degrees of uncertainty around the timing and nature of the impacts of climate change.

In addition to scientific knowledge, practitioners need to be mindful of the importance of the contribution of local knowledge and matauranga Māori to any engagement process. The design of adaptation options and their implementation pathways for sea-level rise requires ecological, social, cultural, economic and political input, particularly at the local scale (Moser and Dilling, 2007; Sheppard et al, 2011). Sharing of knowledge, co-learning and joint exploration of risks and uncertainty through dialogue and collective enquiry will encourage a shared understanding.

Guiding principle 6: Secure committed resources and institutional support

Any community engagement process that aims to address SLR requires adequate support and resources, including:

1 committed and ongoing leadership

2 full support and commitment to ongoing dialogue from key national, regional and local organisations and institutions. This includes local and central government, key industries and institutions whose activities are likely to be impacted by coastal hazards and SLR, or who would be involved in the implementation of adaptation strategies over time

3 ability to establish and maintain a team that contains the required mix of skills and the authority to implement any agreed outcomes (see section 1.4.1). This should include staff trained in technical disciplines, planning and policy, public participation processes (Barisky, 2015), iwi/hapū engagement protocols and science communication

4 ability to enable active iwi/hapū and Māori business participation through existing relationships and jointly agreed mechanisms

5 commitment to a process that enables all stakeholders to easily provide input.

While this kind of engagement process requires significant resourcing, it is likely to enable a good result that will be supported by the community, and provide co-benefits for communities and those who make decisions on their behalf.

Ongoing monitoring and implementation of decisions will also require ongoing resource commitment from the participants and councils in addressing coastal hazard risk (chapter 11).

BOX 8: OTHER ENGAGEMENT GUIDANCE USING SIMILAR GUIDING PRINCIPLES

Future Earth Engagement Principles and Practice: Based on a commitment to co-design and co-produce knowledge in collaboration with societal partners. The aim is to develop solutions-oriented research that responds to the sustainability challenges facing society (see www.futureearth.org/media/future-earth-engagement-principles-and-practice).

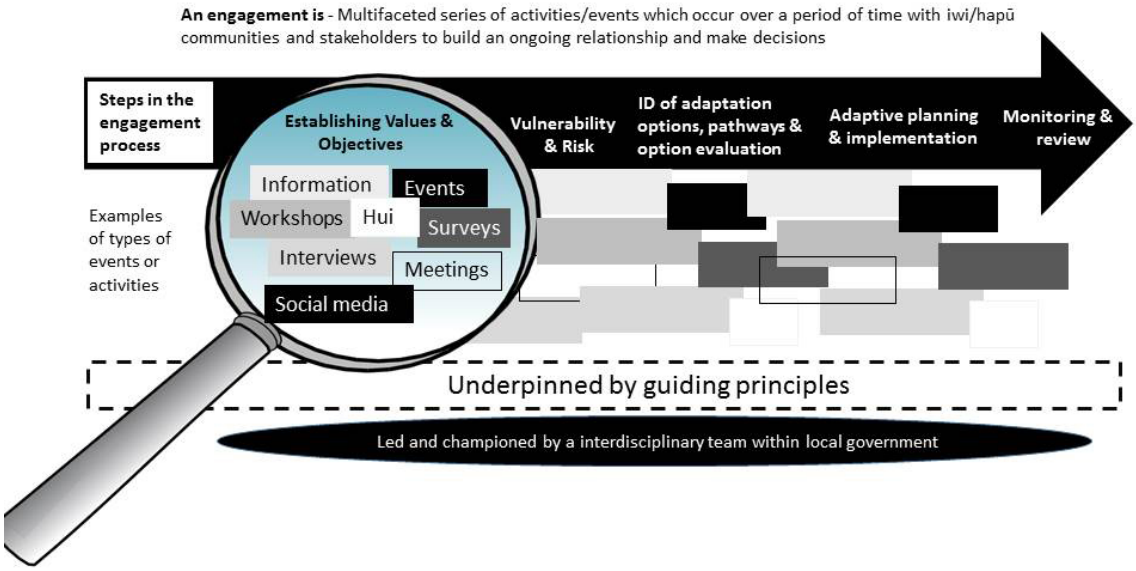
A more theoretical perspective on guidelines is presented in Bryson et al, 2013.

3.5 Designing an engagement strategy in practice

In practice, the 10-step decision cycle recommended in this guidance (figure 1) will require a sequence of engagement activities and events (figure 10) that are undertaken using a collaborative approach, supported by guiding principles and applied by a multi-disciplinary team. Relevant steps will include multiple community, iwi/hapū and stakeholder engagement activities.

These steps are discussed separately in relevant chapters. General details and links to resources are provided in the following sections.

Figure 10: Engagement process following the steps in this guidance

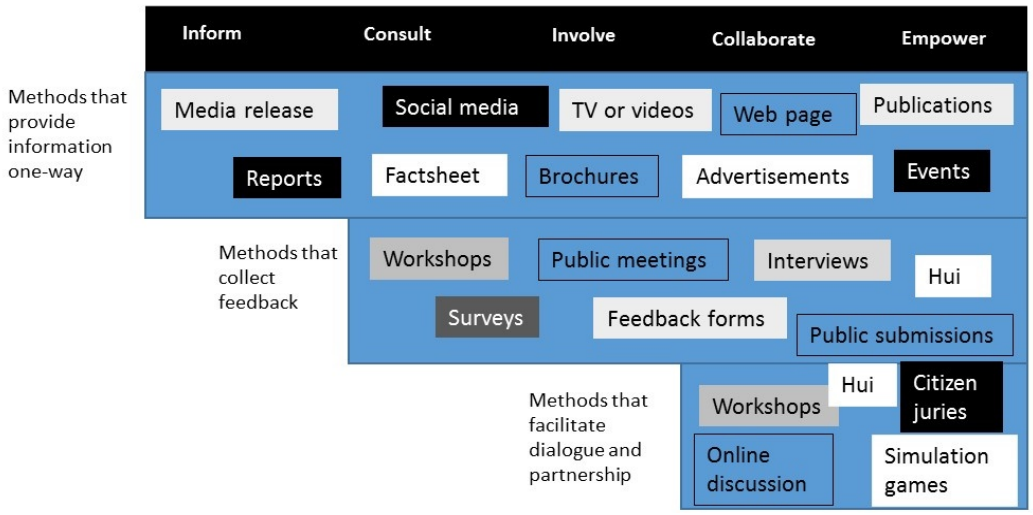


3.5.1 What sorts of activities and events could be used?

Individual activities and events will fit into three broad categories: a) methods that provide one-way information transfer; b) approaches that collate feedback from different social groups; c) methods that facilitate dialogue and partnership to support decision-making (figure 11). Collaborative processes will use the full range of activities. In addition, the sequence of methods should consider what is happening in each part of the 10-step decision cycle – does it involve dialogue, debate or negotiation because each may require different methods (Forester and Theckethil, 2009).

- Where dialogue is necessary, methods that facilitate understanding and help answer the question "what do you mean?" are needed.
- When debate is necessary, suitable methods will enable and moderate the presentation and justification of different arguments. In short, testing "the why is that right?" question.
- Finally, where negotiation is necessary, methods will draw on mediation and conflict-resolution processes and practices so participants can address the question of "what can we do?".

Figure 11: Types of activities and events that fit along the International Association for Public Participation spectrum of participation



A wealth of information is available regarding different types of activities to match each level of participation along the IAP[2] spectrum (box 9). Each has advantages and disadvantages and will be appropriate for different groups of people.

This guidance does not set out a series of steps for engagement because this will restrict the ability and creativity of adaptation teams to decide what is best for their people, circumstances and community, iwi/hapū and stakeholder context.

BOX 9: HELPFUL RESOURCES ON ENGAGEMENT ACTIVITIES AND EVENTS

IAP[2] Tool Box: different methods and their uses	http://icma.org/en/icma/knowledge_network/documents/kn/Document/305431/IAP2_Public_Participation_Toolbox
National Coalition for Dialogue and Deliberation (NCDD)	ncdd.org
Policy Consensus Initiative (now Kitchen Table Democracy)	www.kitchentable.org/tools/practical-guide-collaborative-governance
Everyday democracy resources	www.everyday-democracy.org/
Penn State Centre for Economic and Community Development: Engagement Toolbox	http://aese.psu.edu/research/centers/cecd/engagement-toolbox
CoastAdapt (Beta version) Community Engagement Information Manual 9	https://coastadapt.com.au/sites/default/files/information-manual/IM09_community_engagement.pdf
Consensus Building Institute: tools and resources on conflict resolution, negation and consensus building	http://www.cbuilding.org/
Engaging Queenslanders: A guide to community engagement methods and techniques	www.wombatcreative.com.au/wp-content/uploads/2012/12/engaging-queenslanders-methods-and-techniques_2_.pdf

Key texts

General participation methods:

Chambers R. 2002. *Participatory workshops: A source of 21 sets of ideas and activities*. London: Earthscan.

Forester J. 2009. *Dealing with Differences: Dramas of mediating public disputes*. Oxford: Oxford University Press.

Laws D, Forester J. 2015. *Conflict, Improvisation, Governance: Street level practices for urban democracy*. Abingdon (Oxford): Routledge.

Reid H, Alam M, Berger R, Cannon T, Milligan A. 2009. *Community-based adaptation to climate change* (Vol PLA 60). London: International Institute for Environment and Development.

BOX 9: HELPFUL RESOURCES ON ENGAGEMENT ACTIVITIES AND EVENTS

Social research methodology texts will also help with considering the different options and alternatives.

Engaging with iwi, hapū and whānau:
Harmsworth G. 2005. *Good practice guidelines for working with tangata whenua and Māori organisations: Consolidating our learning*. Palmerston North: Landcare Research. Retrieved from www.landcareresearch.co.nz/publications/researchpubs/harmsworth_good_practice_tanagata_whenua.pdf

Application of IAP[2] spectrum:
Serrao-Neumann S, Harman B, Leitch A, Low Choy D. 2015. Public engagement and climate adaptation: Insights from three local governments in Australia. *Journal of Environmental Planning and Management* 58(7): 1196–1216.

When designing an engagement process, the designers should continually ask themselves if the proposed activity, or series of activities:

1 is in line with the guiding principles

2 suits the target group in the communities, iwi/hapū and stakeholders groups

3 fits the stage of the 10-step decision cycle and achieves the outcomes desired for that step in the process, as well as contributes to the process as a whole.

If these criteria are met, then the activity can form an appropriate part of the process. Where the answer is no, the activity should be reconsidered or redesigned.

3.6 Navigating engagement in this guidance

Engagement with the community, iwi/hapū and stakeholders occurs throughout the decision cycle (figure 1) towards managing responses to coastal hazard and climate change risk and adaptation planning. It can occur at multiple scales and in different ways, matched to the nature of the problem, the purpose or goal of the engagement, the level of agreement in community, iwi/hapū and stakeholder values, and how impacts are distributed over time.

Engagement possibilities, key questions and examples are included in each of the following chapters to match engagement practice with the stages of the 10-step decision cycle (figure 1):

Chapter 7: Establishing values and objectives (what matters most?)

Chapter 8: Vulnerability and risk

Chapter 9: Adapting to changing coastal risks arising from climate change impacts

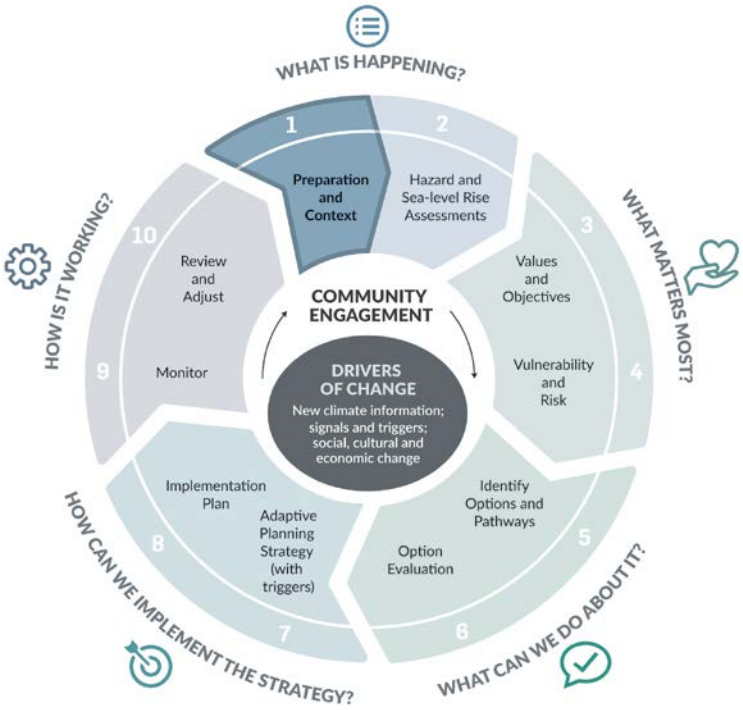
Chapter 10: Adaptive planning strategy and implementation

Chapter 11: Monitoring and reviewing.

4 Understanding and awareness of changing coastal risk

Chapter 4	**Chapter 4 covers:** • inclusion and treatment of uncertainty in decision-making, especially from ongoing sea-level rise • why deep uncertainty comes from the future rate of sea-level rise • why it is important to include and deal with uncertainty in decision-making • why decisions cannot wait until uncertainties are resolved • importance of considering future risk transfer in decisions.
Step 1	**Key tasks** a. Evaluate the types of uncertainties in information available in this guidance and the local and national data, and how they will influence types of decisions made. b. For the type of decision, identify which scenarios to consider and the scale and complexity of hazard, and risk and vulnerability assessments (figure 14). c. When planning for the future under uncertain conditions, consider the risk transfer, legal liabilities and financing consequences of decisions.

Figure 12: Step 1 in the 10-step decision cycle: What is happening? – preparation and context



4.1 Conceptual basis for this guidance

The treatment of uncertainty outlined in the preface is central to this guidance. Continuing sea-level rise (SLR) is certain, and the types of impacts are foreseeable (chapters 1 and 5). There is deep and unavoidable uncertainty, however, about the rate of SLR, its magnitude

and the flow-on consequences for each local coastal area. As much as uncertainties can influence decisions made today or in the future, the effects of SLR must be included in:

- hazard assessments
- risk and vulnerability assessments
- options evaluation and prioritisation
- adaptive pathways
- implementation plans that allow adjustments to be made before impacts are felt.

This is because many possible planning, policy and physical response options exist, and many different values are at stake both now and in the future. Decisions taken today will have consequences on the ability of communities to adapt in the future.

While many adaptation decisions can be implemented through local government planning, policy, building and asset management processes, they need to sit under a wider strategic public–private–council adaptation plan that can be adjusted over time in response to evolving climate change impacts.

In coastal areas affected by hazard risk and climate change impacts, decisions must be made under unavoidable uncertainty (Dessai et al, 2009; Lempert et al, 2003), where:

- parties to a decision do not know or cannot agree on the problem, its boundaries, the outcome sought and the relative importance of interests, and the probability of uncertain inputs to the problem (Lempert et al, 2003; Walker et al, 2013)
- there is dynamic interaction between factors that cannot be considered independently (Haasnoot et al, 2013; Hallegatte et al, 2012), or
- many possible response options exist and different interests are at stake.

These three issues are endemic in coastal settings facing hazard risk and sea-level rise. They mean ongoing engagement must occur between decision-makers and communities about:

- how the coastal system functions (including uncertainty about frequency, magnitude and timing of impacts)
- defining the problem (the hazard risk and vulnerability assessments)
- options and their evaluation for addressing the problem (impacts of options and on whom, costs and financing) and their implementation (adaptive pathways and implementation plans).

An iterative planning process involving affected parties will be needed to decide what may be implemented (Herman et al, 2015) through both the statutory and non-statutory frameworks and funding systems that councils, and those interfacing with council processes, operate within.

Making decisions about responses to climate change impacts differs from decisions made regarding many other issues (box 10). These differences relate primarily to the irreversibility of sea-level rise and the rate, scale and scope of ongoing impacts. These will also vary regionally and locally in New Zealand, creating unequal impacts on communities (Local Government New Zealand, 2016b).

Sea-level rise is a 'game changer' for decisions for coastal areas taken from now. It will challenge the coping capacity of coastal communities and their decision-makers. Sea-level rise is occurring now and is expected to continue for several centuries or more, but reductions in emissions of greenhouse gases in the coming decades can strongly influence the rate of change and ultimate magnitude of the rise (see chapter 5).

The rate at which sea level will rise, and the magnitude of this rise, becomes increasingly uncertain as the timeframe lengthens, because greenhouse gas emission trajectories, especially over the next few critical decades, are unknown (Clark et al, 2016). In addition, the onset and effect of instabilities in polar ice sheet response to continued warming of the oceans and atmosphere creates considerable uncertainty regarding SLR, especially beyond the end of this century (chapter 5). This uncertainty should not constrain decision-making in the near term (out to 2030–50), however, because the uncertainties are much lower in this period than for longer timeframes (chapter 5).

For activities and assets with long lifetimes, which have decision timeframes of at least 100 years or more, a wide set of possible futures needs to be considered. This makes it essential that responses identified today, for whatever timeframe, are flexible and can be adapted in future. These should consider the prospect of transitioning to eventual retreat from the coast in the future. The requirement for adaptation makes ongoing engagement with the communities of interest essential. Councils will reflect what is tolerable now and consider the foreseeable needs of future generations.

BOX 10: IS CLIMATE CHANGE DECISION-MAKING DIFFERENT FROM OTHER KINDS OF DECISION-MAKING?

Climate-related decisions have both similarities and differences with decisions concerning other long-term, high-consequence issues. Commonalities include the usefulness of a broad risk framework and the need to consider uncertain projections of future biophysical and socio-economic conditions. Climate change includes even longer time horizons, however, and affects a broader range of human and earth systems relative to many other sources of risk. Climate change impact, adaptation, and vulnerability assessments offer a specific platform for exploring long-term future scenarios in which climate change is considered, along with other projected changes relevant to long-term planning.

In many situations, climate change may lead to substantial and irreversible outcomes (eg, sea-level rise) that challenge conventional economic tools and environmental policy. In addition, the realisation that future climate may differ significantly from previous experience is still relatively new for many fields of practice (eg, food production, natural resources management, natural hazards management, insurance, public health services and urban planning).

Source: Adapted from FAQ 2.3, Frequently Asked Questions, IPCC (Jones et al, 2014)

Present 'applications' of the standard risk assessment and management process (AS/NZS ISO 31000:2009) include techniques such as likelihood–consequences heat maps and comparison with other natural and human risks to prioritise risk reduction. Applications like these do not easily cope with the long-term changing risk profile facing coastal areas. In particular, likelihood (usually expressed as an occurrence probability) is difficult to address, because SLR will greatly increase the likelihood of reaching damaging coastal hazard thresholds (such as high storm-tide elevations). This causes the likelihood axis of likelihood–consequence heat maps to rapidly saturate out, so that all consequences, no matter how severe, become "very likely" or "virtually certain" (Center for Science in the Earth System, 2007).[53] Furthermore, likelihoods cannot be predicted reliably for long-term SLR (chapter 5).

Instead, assessment and management approaches that explicitly deal with uncertainty and the changing character of risk need to be used in coastal areas (Kunreuther et al, 2013) (chapter 8).

[53] See appendix F for likelihood categories.

Such approaches can assess the risk and consequences, but likelihood of future sea-level rise and climate change impacts cannot be quantified. Rather, the focus should be on 'testing' responses to climate change against a range of future scenarios, before making decisions on pathways to reduce or avoid risk and reduce social vulnerability. This approach allows triggers or decision points to be identified, where the adaptation pathway may be altered in response to any future coastal climate impacts. The change in course (pathway) may be delayed if slower than anticipated SLR occurs, and earlier change may be implemented if SLR is more rapid than expected, or if progress on reducing global emissions is limited.

Adaptive evaluation and decision-making approaches are widely used for dealing with uncertainty in decision-making across different domains (Haasnoot et al, 2011, 2013; Kwakkel et al, 2016; Lempert and Collins, 2007; Lempert et al, 2003, 2006). These approaches (chapter 9) are specifically designed to provide policy direction for problems with high temporal and spatial uncertainty; for example, where the likelihood of sea-level rise by a specified date is unknown (eg, 2050 or 2120), or where the magnitude or rate of sea-level rise cannot be determined accurately.

4.2 Why is it important to include uncertainties in adaptation planning?

If coastal adaptation planning does not intentionally account for uncertainties, much of the evidence and the risk of unexpected consequences from our decisions would not be considered (Lourenço et al, 2014).

Guiding principle

- If the risk is **underestimated**, the consequences could be financial, loss of property and livelihood, social and economic disruption, inequities created regionally and accumulated nationally, loss of environmental services and possible loss of life.
- If the risk is **overestimated** for a specific timeframe, the repercussions will be temporary, because sea level will continue to rise (it is only a matter of time before the adaptation threshold is reached for those exposed to the risk), but social and economic penalties occur in the interim.

By not considering a full range of plausible outcomes, decisions could commit the community to an increase in risk exposure and make future adaptation more complex and expensive, including under- and over-adaptation. This would increase the institutional risk of being unprepared and being caught unaware, when adaptive management options could have been employed.

The non-linearity, variability and uncertainty of climate impacts require planning systems that are flexible enough to adapt to unexpected and extreme events that can happen at any time (Holling, 1973).

Guiding principles

Simply using a single value (or 'best estimate'), for example, an increase of X per cent on top of an existing or future state (eg, 5 per cent higher wave heights) at a location or, more critically, a single sea-level rise number will not enable plausible alternative future states (both high and low) and associated uncertainties and sensitivities to be considered. This in turn could be critical for long-lived activities or assets, or create lock-in and path dependency (Swart et al, 2014).

Knowledge of the range of plausible futures in which adaptation actions will be set and implemented is essential. Each action will have different levels of knowledge surrounding it. Therefore, it is important to understand and make transparent the nature of the knowledge related to the evidence:

- what is known now, and known unknowns (eg, you know wave heights may increase but have no local projections for sea-level rise over this century, but could explore sensitivity to a plausible range)
- what is unknown (eg, sea-level rise rate at upper end magnitudes from ice sheet instabilities)
- what is uncertain (eg, timing of extreme events and adverse climate cycles).

Scenarios can be used to consider the range of plausible futures (chapters 5 and 6), but even that range may not necessarily cover the change that eventuates, which is another reason for using a dynamic adaptive pathways planning approach (chapters 9 and 10).

4.3 Analysing, characterising and dealing with uncertainty

Analysing, characterising and dealing with uncertainty is an integral part of establishing and implementing climate change adaptation decisions (Jones et al, 2014).

When using coastal hazard assessment information in adaptation decision-making, four levels of uncertainty exist that lead to different types of decisions and policies (Walker et al, 2003).

Future coastal hazards:

1 are knowable (*little uncertainty*) = predict and act policies

2 will behave probabilistically or stochastically in much the same way as in the past (*statistical uncertainty*) = 'trend-based' policies

3 are well described by a few overarching scenarios (*scenario uncertainty)* = 'static robust' policies

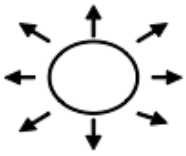
4 are unknown or disagreed upon by experts and/or stakeholders with no consensus on what the future might bring (*deep uncertainty)* = adaptive and iterative policies.

Typically, some or all of these types of uncertainty will be incorporated during practical decision-making. Examples for coastal hazard assessments, considering these different types of uncertainty, are given in chapter 6.

Making the type of uncertainty transparent helps identify which of the four assessment types the decisions are operating in. For example, if the decision has a lifetime beyond 100 years, the upper levels of SLR and extreme events will require development of scenarios for analysis and

flexible pathways, because they operate within a deep uncertainty (recognised ignorance) domain. Figure 13 shows this in more detail.

Figure 13: Type of uncertainty

		LEVEL					
			Level 1	Level 2	Level 3	Level 4	
LOCATION	Context	Complete Certainty	A clear enough future	Alternate futures (with probabilities)	A multiplicity of plausible futures	Unknown future 	Total Ignorance
	System Model		A single (deterministic) system model	A single (stochastic) system model	Several system models, with different structures	Unknown system model; know we don't know	
	System Outcomes		A point estimate for each outcome	A confidence interval for each outcome	A known range of outcomes	Unknown outcomes; know we don't know	
	Weights on outcomes		A single set of weights	Several sets of weights, with a probability attached to each set	A known range of weights	Unknown weights; know we don't know	

Source: After Walker et al (2013)

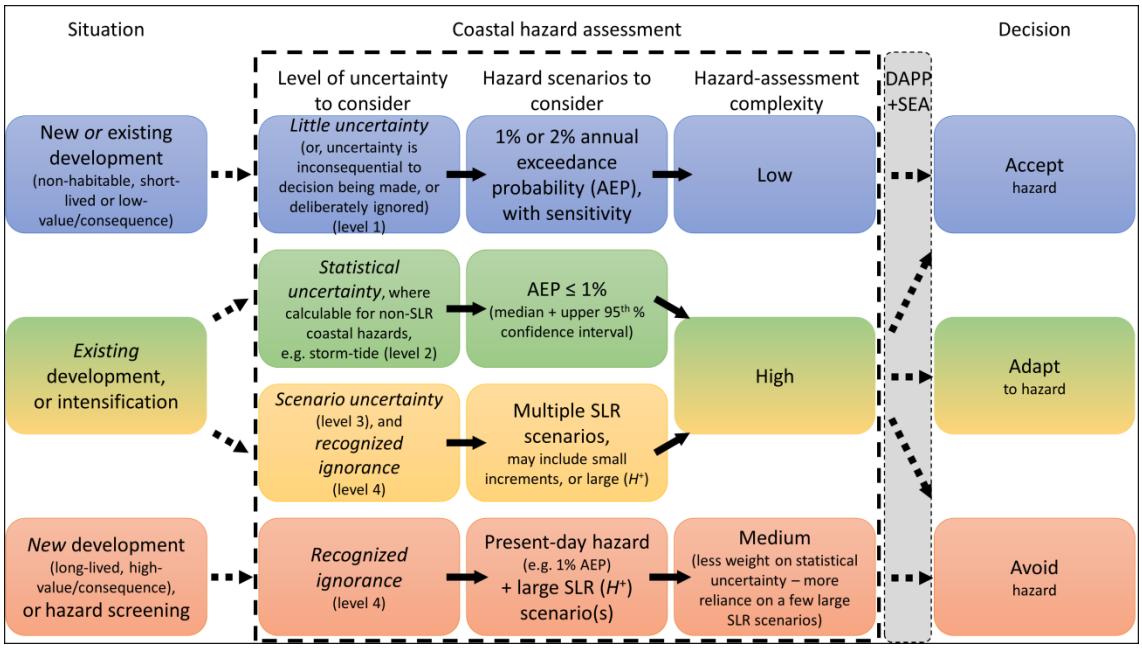
To take this further, important distinctions between the types of uncertainty should be recognised (Walker et al, 2003). For example, decision uncertainty (associated with human judgements about future greenhouse gas emissions), natural variability (climate–system variability) and scientific uncertainty (data gaps, incomplete understanding or insufficient computation power of climate–ocean and impact models). The most policy relevant of these levels of uncertainty for a particular decision is shown in figure 14 and chapter 6.

In the context of sea-level rise, however, the 'level' of uncertainty (figure 13) is the uncertainty that will be decision relevant for all stages of the assessment and planning process – hazard assessment, vulnerability and risk assessments, options evaluation (eg, cost effectiveness and efficiency assessments, multi-criteria analysis), adaptive pathways planning and development of implementation plans for adaptation over timeframes of at least 100 years.

The sea-level rise uncertainty for timeframes extending beyond 2100[54] arises mainly from the *unknown future rate and magnitude of sea-level rise*, which locates it in the 'deep uncertainty', high-consequence range. This is because likelihoods cannot be assigned to SLR projections (nor can a 'best estimate' be predetermined); scenarios and systematic expert elicitation will be required to assess the range of future scenarios that could eventuate (both fast and slow SLR) and their likely consequences (see figure 14).

[54] Detailed Intergovernmental Panel on Climate Change (IPCC) SLR projections only go up to 2100 (but have been extended for scenarios in this guidance in chapter 5).

Figure 14: Uncertainty framework for coastal hazard assessments to support the dynamic adaptive planning pathways (DAPP) process, showing a logical flow from the situation, to the related level of uncertainty as determined by the situation, the hazard scenarios to model, the likely hazard modelling complexity, and the possible decision type



See chapter 6 for relevance to selection of hazards scenarios. Note: AEP = annual exceedance probability; SLR = sea-level rise. A distinction is drawn (represented by the dashed arrows and dashed box) between the situation, the coastal hazard assessment process, the DAPP process and socio-economic assessment (SEA), and the decision type. Adapted from: Stephens et al. (2017)[55]

4.4 Why can decisions not wait until uncertainties are resolved?

Waiting until uncertainties are reduced before making decisions, or holding back on making decisions under uncertain conditions, is usually not viable or acceptable to those who are most exposed to the risk (nor for future generations (chapter 2)). With several sources and types of uncertainty, future coastal climate change impacts will not be known with precision in the foreseeable future (Kunreuther et al, 2013) – particularly if runaway ice sheet instabilities or other non-linear climate–ocean responses occur.

Uncertainties cannot be eliminated and, to some degree, research is unable to define them – and, in some cases, has increased uncertainties.[56] For example, some uncertainties cannot be reduced or simplified (eg, the upper end of sea-level rise if global surface temperature rise is greater than 2°C above pre-industrial levels (chapter 5)), because they are related to the chaotic nature of natural systems, their interactions and the feedback mechanisms that exist between them. As a result of climate change, they cannot be fully predicted, nor a likelihood established, because neither the timing nor the rate of change can be resolved. Second-guessing the effect of future emissions mitigation is also difficult to do, unless a concerted global effort at reducing emissions occurs over the next decade or so (Clark et al, 2016).

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55 Stephens, S., Bell, R., Lawrence, J. (2017) Applying Principles of Uncertainty within Coastal Hazard Assessments to Better Support Coastal Adaptation. *Journal of Marine Science and Engineering*, 5(3): 40.

56 For example, discovery of extensive areas on the Antarctic continent where bedrock surface is now known to be well below sea level, with the potential for greater runaway ice-sheet response (see appendix D).

These uncertainties have similarities to other irreducible uncertainties that decision-makers deal with every day, such as gross domestic product growth over the coming decades, population growth projections, or traffic volumes likely to occur over the 50–100-year life of a road. There are differences for decision-makers in coastal settings, however, because sea-level rise and increased frequency of extreme events are likely to have widespread, disruptive, concurrent (at several locations in a district, region or nationally at the same time) and cumulative consequences (impacts will accumulate and affect the ability to adapt to repeat hazard events), even if severity varies around the country.

This makes a difference to how decisions need to be made today; especially for long-lived decisions that lock in a pathway or response that may not be easily adjusted before the costs and consequences are upon us, and that may unnecessarily hasten the need for retreat. Even a small sea-level rise (eg, 0.2–0.4 metres by 2040–60) may impact on the function of underground services, drainage and stormwater networks, and on roads that low-lying communities rely on for everyday use and livelihoods. In the long term, sea level will continue to rise for at least several centuries (with high confidence determined by the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5), (IPCC 2013a)), but with deep uncertainty on the rate of rise (chapter 5).

Guiding principle

For near-term decisions (eg, with lifetimes up to 2040–60), because the uncertainty range is smaller (sea-level rise range of 0.2–0.4 metres), sea level consideration should not delay initial decision-making processes.

Near-term decisions such as these should build in flexibility, to enable changes to pathways or measures that can accommodate high-end sea-level rise over longer timeframes. They need to be able to include the impact of sea-level rise increasing the frequency and magnitude of extreme storm-related inundation and erosion.

On the other hand, flexible adaptive management approaches can also cover the situation where the rate of sea-level rise is slower than anticipated for the planning period. In this case, planned response options can be delayed (although the decision-point threshold remains in place, providing ongoing certainty for stakeholders).

Understanding the consequences of acting and not acting is an essential requirement of local government decision-makers. Making decisions under uncertain conditions will always involve subjective evaluations of available knowledge. Using simple mathematics, Lewandowsky et al (2014) showed that greater uncertainty implies a greater probability of adverse consequences (box 11) – so not acting in the face of uncertainty implies considerable risk. Instead, widening the range of possible future conditions being considered (to account for uncertainty) is more likely to result in robust decision-making around planned alternative or staged response options, and provide for adjustments over time, depending on how the future evolves.

BOX 11: HOW UNCERTAINTY AFFECTS ADAPTATION AND MITIGATION

- Greater uncertainty about climate change implies a greater probability of adverse consequences.
- The potential for large changes increases with uncertainty, because greater uncertainty entails a greater likelihood of extremely high values of sensitivity.
- Greater uncertainty about climate sensitivity translates not only into greater expected damage, but it also implies that greater damages are more likely to arrive sooner.
- Unresolved technical issues amongst scientists have meant it is difficult to reduce uncertainty and confidence in temperature and sea-level rise (SLR) projections, leading to greater chances of exceeding a global temperature threshold, such as the 2015 Paris Agreement.
- When uncertainty about SLR is non-zero, then irrespective of the assumptions made about the distribution of SLR, the required protective response increases, deviating rapidly and in an accelerating manner from the anticipated mean SLR.
- Greater uncertainty about SLR translates into a requirement for a larger range of protective or adaptive responses (compared with a narrower uncertainty range).

Source: Lewandowsky et al (2014)

Guiding principle

It is essential that plans and assets designed now have the capacity to be flexible and adaptable (including the prospect of eventual retreat from low-lying coastal areas). Flexibility and adaptability should be factored into decision-making whatever the timeframe, because of the potential lock-in of development pathways from decisions taken today. This flexibility will increase the ability to adjust in the future.

4.5 Risk transfer

Guiding principle

When planning for the future under uncertain conditions, it is important to also consider the risk transfer, legal liabilities and the financing consequences of decisions.

Uncertainties typically play out through a number of risk transfer mechanisms, including the transfer of risk from individuals and the wider community today to future generations. Potentially, some risks can be transferred to risk-transfer agencies, such as the insurance sector and the Earthquake Commission,[57] which may not be sufficiently underwritten for the scale and scope of future climate change consequences. Local government has statutory and fiduciary duties to its communities to reduce hazard risk, mandated from the New Zealand

[57] Coverage for sudden land slips, flood damage to land around a dwelling, and tsunami damage to dwellings are included; but creeping hazards such as incremental coastal erosion or coastal inundation damage to assets or buildings are not.

Coastal Policy Statement 2010, the Civil Defence Emergency Management Act 2002 and the Local Government Act 2002 (chapter 2).

The impact of decisions taken today, for example, on the location of a subdivision on the coast or intensifying the use of exposed low-lying land (eg, increasing property values, due to upgraded dwelling or infill development), is unlikely to be felt by those making the decisions or current property owners.

Local government responsibilities (chapter 2) to reduce risk or 'not increase risk' in these locations mean whole communities could potentially bear the cost of the future response (eg, increased rates, higher insurance premiums, or even the withdrawal of insurance), which will affect everyone in such locations. Consideration of these risk transfers when making decisions today can minimise the scale of future risk transfer by reducing risk exposure (Insurance Council of New Zealand, 2014). Further inequities are likely if considerations like these are ignored. This can have the effect of intensifying existing inequities and shifting the burden to the welfare state and taxpayers (Handmer, 2008).

Local government also develops and manages a considerable portfolio of public assets, utilities and infrastructure. Risk financing and transfer of these long-lived assets has been highlighted following the Canterbury earthquakes, leading to a guide for local government (Local Government New Zealand, 2016a). In coastal areas facing ongoing sea-level rise, risk financing will also need to consider climate change impacts in an adaptive management framework.

4.6 Summary

It is important to consider uncertainty in decision-making because:

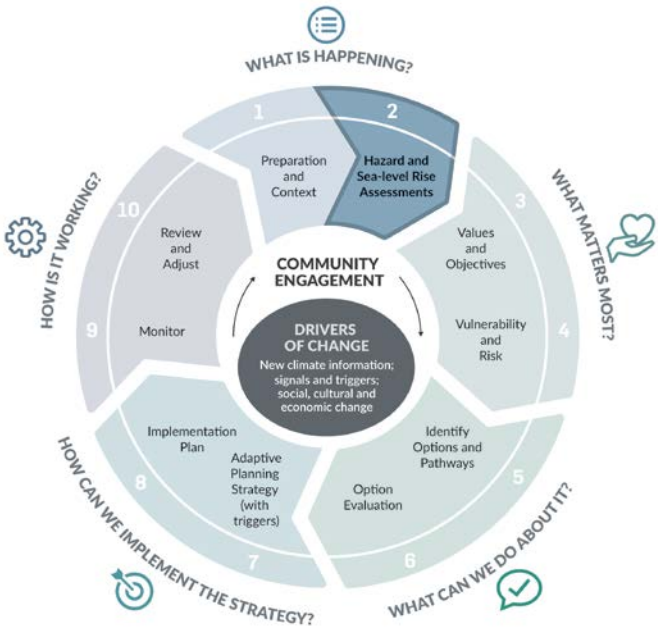
- some uncertainty is inherent in all evidence, and uncertainty increases in longer term projections
- greater uncertainty about climate change implies a greater probability of adverse consequences
- uncertainties are relevant for decisions that are long lasting and/or create path dependency, and so the potential for surprises needs to be considered
- adequately considering uncertainty reduces the potential for under- and over-adaptation
- considering uncertainties allows relevant and changing risks to be included in evidence.

There are ways of integrating uncertainties and changing risk in the decision-making cycle, in particular, using enhanced risk assessment0, evaluation and management techniques. These have been used widely overseas in a number of domains and are being used increasingly for decision-making at the coast where sea-level rise and related impacts are ongoing (chapter 9).

5 Changing climate and future projections for coastal areas

Chapter 5	**Chapter 5 covers:** • certainty of climate change and coastal impacts from sea-level rise • evidence base for historic and recent sea-level rise (global and New Zealand) • context for representative concentration pathway (RCP) scenarios and the effect of reducing global emissions on sea-level rise • derivation of sea-level rise guidance for New Zealand to 2120–50 • guidance on projected changes in waves, storm surge and winds.
Step 2	**Key tasks** a. Set up sea-level rise scenarios over appropriate timeframe for location and region – consider whether to include vertical land movement adjustment. b. If using transitional minimum values or scenarios (allowances), select the one relevant to the type or category of development. c. Determine the range of sea-level rise increments, the sensitivity range for waves, storm surge and wind and timeframes for hazard assessments (chapter 6).

Figure 15: Step 2 in the 10-step decision cycle: What is happening? – hazard and SLR assessments



5.1 Certainty of climate change so far

Heat is being trapped in the atmosphere by increasing concentrations of carbon dioxide and other greenhouse gases, and the climate–ocean system has responded. One of the major and most certain (and so foreseeable) consequences is the rising sea level (Parliamentary Commissioner for the Environment, 2015).

The Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report (AR5) as four volumes in 2013/14 (see appendix C for more details about the IPCC and its assessments).

IPCC AR5 found that warming of the climate system is unequivocal, and many of the changes observed since the 1950s are unprecedented over timescales of decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished and sea level has risen, with an attendant rise in global carbon dioxide emissions (IPCC, 2014a).

The IPCC concludes that anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever experienced in human times. Present levels of the main greenhouse gas components[58] (eg, carbon dioxide, methane and nitrous oxide) are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been observed throughout the climate system and are *extremely likely*[59] to have been the dominant cause of the warming observed since the mid-20th century (IPCC, 2014a).

Progress has also been made in understanding the observed changes in the climate–ocean system, and is reflected in our improved understanding of the uncertainties around the emerging impacts, for example:

- the global sea-level rise (SLR) since 1993 now closely matches the sum of observations of the contributing drivers (Church et al, 2013a)
- broader and more robust assessment of the relationships between warming and observed changes, such as ocean heat uptake, glacier and ice sheet response and sea-level rise, has been possible, better underpinning future projections (Church et al, 2013a; IPCC, 2013a).

5.2 Observations and trends for sea-level rise (global and New Zealand)

Providing guidance on sea-level rise projections (section 5.7) requires an understanding and awareness of both the historic and present New Zealand trends in rising sea level in the global context, and what is causing the recent increases in the rate of rise.

The rise in sea level is of great relevance for long-term decisions made in coastal areas, for two main reasons.

1. The long-term impacts on coastal populations, developments and environments are potentially large (eg, Hinkel et al, 2014; Nicholls et al, 2011b), because past coastal developments were built on the premise of a relatively 'stable' sea level.
2. The sea level response to warming of the Earth's climate system makes it an integrated global indicator – 90 per cent of the energy added to the climate system ends up in the oceans (Rhein et al, 2013). Observed sea-level rise, however, needs to be interpreted in light of substantial lags (decades to millennia) in the ongoing response to warming of the oceans and melting of glaciers and ice sheets (Dangendorf et al, 2014; IPCC, 2013a).

Rising sea level in past decades is already affecting human activities and infrastructure in coastal areas, with a higher base mean sea level contributing to increased vulnerability to storms and tsunami. Key impacts of rising sea level (chapter 6) are:

- gradual inundation of low-lying marsh and adjoining dry land on spring tides

58 Excluding water vapour.

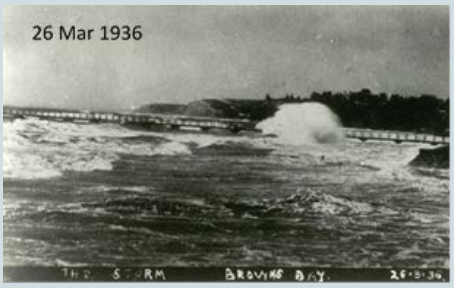
59 Phrases in italics are derived from IPCC's calibrated language on expressing: a) confidence (from *very low* to *very high*) and b) certainty (from *exceptionally unlikely* to *virtually certain*) in the findings in the AR5 (Mastrandrea et al, 2010).

- escalation in the frequency of nuisance and damaging coastal-inundation events
- exacerbated erosion of sand and gravel shorelines and unconsolidated cliffs (unless sediment supply increases)
- increased incursion of saltwater in lowland rivers and nearby groundwater aquifers, raising water tables in tidally influenced groundwater systems.

These impacts will have increasing implications for most development in coastal areas, along with environmental, societal and cultural effects. Local government road and 'three-waters' infrastructure will also be increasingly affected, such as wastewater treatment plants and potable water supplies, besides capacity issues with stormwater and overland drainage systems.

With a sea-level rise of around 0.2 metres since 1900, low-lying areas of New Zealand are seeing an increased incidence of coastal storm inundation (Parliamentary Commissioner for the Environment, 2014, 2015; Stephens, 2015). Box 12 outlines the role of a background increase in mean sea level, comparing the two largest recorded coastal inundation events on the east coast of Auckland in 1936 and 2011.

BOX 12: ROLE OF SEA-LEVEL RISE INCREASING COASTAL INUNDATION EVENTS IN AUCKLAND



In Auckland, the highest storm-tide level on record for the 20th century (from 1925) occurred late morning on 26 March 1936. A cyclonic low-pressure storm generated a storm surge from strong north-easterlies during the day, and barometric pressures below 997 hPa, coinciding with a high perigean spring or 'king' tide. Some coastal flooding occurred and waves severely damaged the Browns Bay Wharf (photo above).

History repeated late morning on 23 January 2011, with a similar type of low-pressure storm (ex-tropical cyclone *Wilma*) on the back of a perigean spring tide, leading to damaging coastal inundation of low-lying areas of Auckland.

Both storms had a similar annual exceedance probability (1–2 per cent annual exceedance probability), relative to the mean sea level at the time of the events. The 2011 event (2.38 metres AVD-46), however, was 0.13 metres higher than the 1936 event (2.25 metres AVD-46), causing deeper coastal flooding, including houses and road closures. Most of the difference in peak water level for these similar storms is attributable to the 0.12 metre rise in sea level in Auckland (trend: 1.6 millimetres per year) over the intervening 75-year period. More minor coastal inundation events have also occurred in the last five years (particularly in eastern beach areas), plus a further moderate flooding event in April 2014 (ex-tropical cyclone *Ita*), with the increasing frequency of events symptomatic of ongoing sea-level rise.

Source: Tide gauge data (Ports of Auckland Ltd, Auckland Council); Barnett (1938). Photo credits: (left) North Auckland Research Centre, Auckland Libraries, E0345; (right) B Eitelberg

5.2.1 Types of sea-level rise

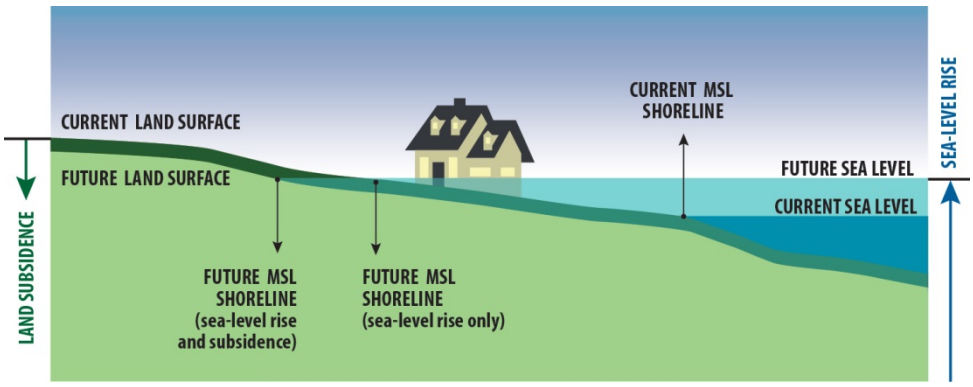
This guidance uses information on three types of sea-level rise for both observations and projections:

- absolute (or eustatic) rise in ocean levels, measured relative to the centre of the Earth, and usually expressed as a global mean (which is used in most sea-level projections)
- offsets (or departures) from the global mean absolute sea-level rise for a regional sea, for example, the sea around New Zealand. Significant variation can occur in response to warming and wind patterns between different regional seas around the Earth
- local (or relative) sea-level rise, which is the net rise from absolute, regional-sea offsets and local vertical land movement, measured relative to the local landmass. Local or regional adaptation to sea-level rise needs to focus on this local rise.

The first two types of sea-level change are measured directly by satellites, using radar altimeters, or by coalescing several tide gauge records after adjusting for local vertical land movement and ongoing changes in the Earth's crust following the last Ice Age.[60]

Local sea-level rise is measured by tide gauges. One advantage of knowing the local SLR from these gauge measurements is that this directly tracks the sea-level rise that has to be adapted to locally or over the wider region represented by the gauge. If, for instance, the local landmass is subsiding, then the local (relative) SLR will be larger than the absolute rise in the adjacent ocean level acting alone, as shown schematically in figure 16. This situation, with local subsidence exacerbating the sea-level rise locally, is occurring in the lower North Island (from co-seismic slow-slip events), in the southern Firth of Thames, and possibly in other local areas not currently instrumented.

Figure 16: Difference in mean sea level (MSL) shoreline between absolute and local (relative) sea-level rise where land subsidence occurs



Graphics: A Wadhwa, NIWA

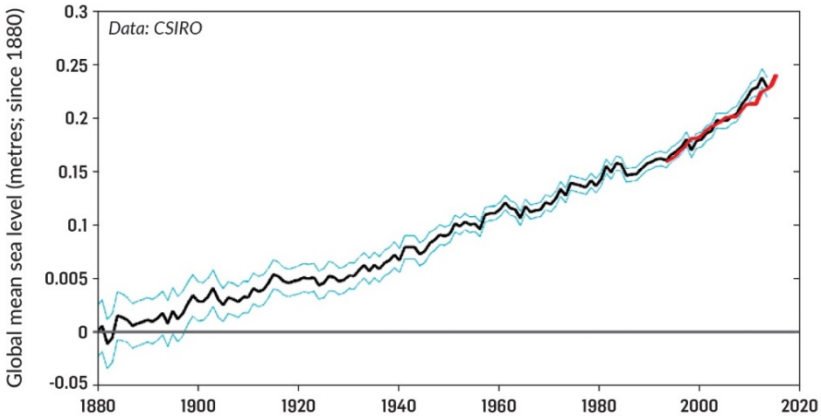
5.2.2 Global mean sea-level rise

Changes in rate of rise

After relative stability in sea level over the past 2000–3000 years, with small rates of sea-level change of up to ±0.2 millimetres per year (mm/yr) (Kopp et al, 2016), global sea level began to rise in the late 1800s. The steady rise in global mean sea level (MSL) since then is shown in figure 17, based on updates of the data from Church and White (2011).

60 The scientific term is glacial isostatic adjustment (GIA).

Figure 17: Cumulative changes in global mean sea level since 1880, based on a reconstruction of long-term tide gauge measurements to end of 2013 (black) and recent satellite measurements to end of 2015 (red)



Note: Lighter lines are the upper and lower bounds of the likely range (±1 standard deviation) of the mean sea level from available tide gauges, which depends on the number of measurements collected and the precision of the methods. Source: Tide gauge data Church and White (2011) updated to 2013 (US Environmental Protection Agency, 2016); satellite data adjusted for glacial isostatic adjustment and inverted barometer (CSIRO, 2016)

From a synthesis of scientific publications, the Intergovernmental Panel on Climate Change determined that it is *very likely* that the mean rate of globally averaged sea-level rise was 1.7±0.2 millimetres per year between 1901 and 2010, producing a total rise in global sea level over that period of 0.19 metres (±0.02 metres).[61] A slightly higher annual rise of 2.0±0.3 millimetres per year occurred in the 40-year period from 1971 to 2010 (Church et al, 2013a).

Contributors to global sea-level rise

As the temperature of the Earth's atmosphere changes so does sea level, although with a lagged response. Rising atmospheric temperature and sea-level change are linked by two main processes.

1 **Volume increase:** As ocean water warms, its volume expands slightly – an effect that is cumulative over the entire depth of the oceans. This is converted mainly into a height increase as the oceans are largely constrained by continental coastlines (despite inundation of low-lying land areas).

2 **Mass increase**: Changes in the land-based volumes of ice and water on land (namely glaciers and ice sheets, and to a lesser extent the net change in freshwater budgets) have led to an increase in the mass of water in the ocean, especially as ice stores diminish with increasing surface and ocean temperatures.

The various specific contributors to global, regional or local rise in sea level for the recent past and into the foreseeable future are discussed further in appendix D.

A recent update by Chambers et al (2016) covering the period 1993–2013 found that the sea-level rise budget from the sum of contributors closed to within 0.2 mm/yr of the global trend. Around 40 per cent of the trend was from thermal expansion of the oceans and 60 per cent from an increase in ocean mass (eg, glaciers, ice cap, ice sheets, hydrology), with an acceleration in the contributions from polar ice sheets over the last decade.

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61 A range of estimates have been made of the historic rate (1900–90) from 1.2 millimetres per year (mm/yr) to 1.9 mm/yr using various sets of tide gauges, processing to remove vertical land motion and the reconstruction of global tide gauge records (Hamlington et al, 2016b), with a more recent paper (Thompson et al, 2016) confirming the global average sea-level rise rate of around 1.7 mm/yr.

Anthropogenic influence

Recent studies have demonstrated that the anthropogenic contribution to the observed sea-level rise in the 20th century has been around 45–50 per cent (Dangendorf et al, 2015; Kopp et al, 2016). The contribution since 1970 has risen to 69 per cent (±31 per cent) of the observed increase in global mean sea level (Slangen et al, 2016b).

Human activities have also influenced local sea-level rise, through activities such as groundwater pumping, which in some coastal cities has caused subsidence and a larger relative sea-level rise locally (Marcos et al, 2016).

While uncertainties remain, particularly for the first half of the 20th century, the ability to explain the observed global MSL changes and the reasons for them gives greater confidence in understanding sea-level change and our ability to project future change (Church et al, 2016).

Recent accelerated trends from satellite data

Sea surface heights measured by radar altimeters on a series of satellite missions (TOPEX/Poseidon; Jason 1, 2, 3; Sentinel-3), have provided a consistent and continuous ocean coverage[62] of sea level since 1993 (known as the 'satellite era').

The present trend in global average absolute MSL from 1993 to May 2016, based on the CSIRO analysis of satellite altimeter data,[63] is 3.3±0.1 mm/yr, shown as the red line in figure 17. This rate of increase, averaged over the past 23 years, is nearly double the global average rate over the 20th century based on hundreds of sea level gauges (Church and White, 2011). A recent comparison with global tide gauges (Watson et al, 2015) over the satellite era shows a trend of between 2.6–2.9±0.4 mm/yr (depending on the adjustment of gauge records for vertical land movement).

Several studies have been undertaken to determine whether this increase during the satellite era is a definite or statistically significant acceleration in sea-level rise, and what has caused it (eg, Clark et al, 2015; Marcos et al, 2016; Slangen et al, 2012; Watson et al, 2015; Zhang and Church, 2012). In summary, natural climate variability from multi-decade climate cycles, especially the 20–30 year Inter-decadal Pacific Oscillation (IPO) (which changed phase around 1999, part-way into the satellite era), has contributed to part of the increased rate of rise. However, it is clear that anthropogenic climate change is also contributing an increasing proportion of modern sea-level rise (see previous subsection, 'Anthropogenic influence'). Watson et al (2015) determined a small acceleration from 1993 to mid-2014, comparable to the accelerated loss of ice from Greenland and larger than the 20th-century acceleration.

To ensure the separation of decadal-scale variability from the regional trends, and definitively assess long-term climate shift, a longer time series from the satellite altimetry is still required. There are also signs that a shift back to the positive-phase of the 20–30 year IPO may be occurring, with short-term sea level trends likely to decrease from their current high rates in the tropical western Pacific (Hamlington et al, 2016a).

5.2.3 Sea-level rise for New Zealand waters

Global average sea-level rise (see previous section) is an indicator statistic for the effects of overall climate change on the world's oceans. There is, however, considerable variability in sea-level rise between regional seas. This is influenced by variability from climate cycles, for

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62 Satellite tracks cover the world's oceans from latitudes 66°N to 66°S.

63 See www.cmar.csiro.au/sealevel/sl_hist_last_decades.html. Rate includes adjustments for both inverse barometer and glacial isostatic adjustment.

example, for the Pacific from the two- to four-year El Niño–Southern Oscillation and the longer 20–30 year IPO (see supplementary information sheet 8 in appendix J on long-period mean sea level fluctuations).

Acceleration in sea-level rise in New Zealand started around 1900, based on analyses of marsh sediments from Otago (Gehrels et al, 2008). This historic change in the rate of rise, which occurred globally in the late 1800s, is not apparent in New Zealand tide gauge records because the earliest reliable and continuous records only date back to the start of the 20th century (1899–1903) at the four main ports of Auckland, Wellington, Lyttelton and Dunedin (Hannah, 2004).

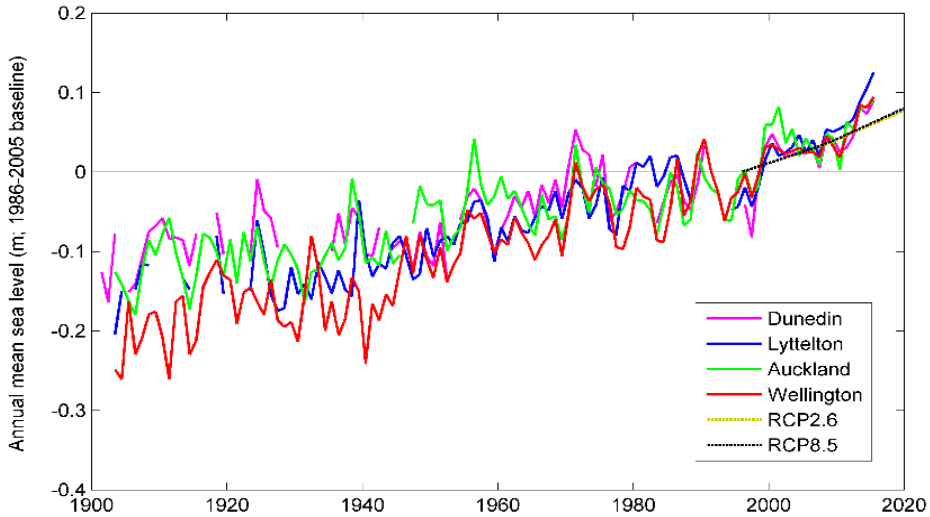
Historic sea-level rise around New Zealand

Changes in annual local MSL at the four main ports in New Zealand are shown in figure 18. MSL is plotted relative to the average for each time series over the same 1986–2005 baseline period used for IPCC AR5 projections. The initial period of IPCC global mean projections of SLR for representative concentration pathway (RCP) 8.5 and RCP2.6 scenarios (section 5.5.3) are also shown for a general comparison.

Considerable variability occurs from year to year, influenced by seasonal changes, the two- to four-year El Niño–Southern Oscillation and the IPO over 20–30-year cycles. The notable rapid rise in SLR in 1999 across all port sites (figure 18) is a result of a regime shift to the negative phase of the IPO.

Climate variability masks the underlying rise caused by climate change. This requires long records to extract robust trends, and also may require one or two decades more of monitoring to confirm which sea-level rise scenario is being followed (because there is little difference at present between scenarios – figure 18).

Figure 18: Change in annual local mean sea level for the four main ports from 1900–2015, and initial global mean sea-level rise projections for RCP2.6 and RCP8.5 to 2020



Relative to the average mean sea level over the baseline period 1986–2005 (used for Intergovernmental Panel on Climate Change Fifth Assessment Report projections of sea-level rise, with mid-point at 1996). Source data: Church et al (2013a); Hannah and Bell (2012), updated by Hannah (2016).

Trends from these long-term port records, along with inferred trends from six other gauge sites used to establish local survey datums last century, were derived by Hannah and Bell (2012) for records up to and including 2008. The average trend for the local or relative SLR at the four main ports up to 2008 was 1.7±0.1 mm/yr, ranging from a local rate of 1.3 mm/yr at Dunedin to 2.0 mm/yr in Wellington.

Adding on the average glacial isostatic adjustment (GIA) for New Zealand, due to post-Ice Age rebound of the Earth's crust of around 0.3 mm/yr (Hannah and Bell, 2012) yields an absolute SLR of around 2.0 mm/yr for New Zealand ocean waters. This is at the upper end of observations of global mean SLR of 1.7±0.2 mm/yr from 1900 to 2010 from the IPCC AR5 (Church et al, 2013a).

The close comparison of global and New Zealand average historic rates means that projections of future sea-level rise by the Intergovernmental Panel on Climate Change and other peer-reviewed sources, which are generated as global means, can generally be adopted for overall use in New Zealand. Small local adjustments for significant local vertical land movement may be needed, however, along with small increases in the projections for the south-west Pacific region (relative to the global mean projections).

Updates for this guidance of the derived local sea level trends with standard deviations for all 10 gauge sites analysed by Hannah and Bell (2012) have included local MSL data to the end of 2015 (Hannah, 2016) and are shown in figure 19.[64] The average of these local SLR trends up to 2015 is close to 1.8 mm/yr.

When comparing locations, there is a noticeable spread of trends in local SLR, ranging from 1.37 mm/yr for Port Taranaki to 2.23 mm/yr at Wellington. These spatial differences are attributable to a mix of factors, including:

- local physical processes and aspects inherent in the data records
- some past unresolved datum or vertical movements of the gauge platform
- variations in vertical land movement (mostly unknown over the record)
- shorter data-record spans outside the four main ports (also reflected in the standard deviations)
- different time periods for the measurement record.

To continue maintaining the integrity of these gauge records for extracting trends, rigorous measurement, survey control and processing protocols need to be followed, and a wider network of continuous GPS sensors deployed in coastal areas to measure vertical land movement.

Local SLR trends at the four main ports have also been analysed by Hannah (2016) for post-1960 trends and compared with the earlier trend, as listed in table 7.

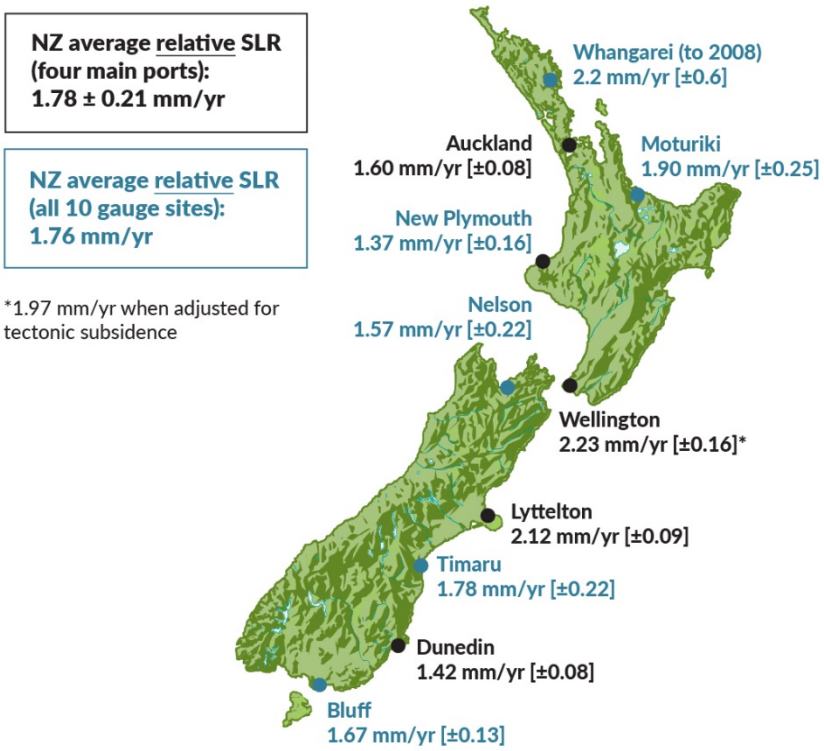
For comparison purposes, the annual local MSL for each port was processed as three different data sets; that is, the full data set, the start of the data set to 1960 and then the more recent data from 1961–2015. Two reasons exist for this 1960 split:

- First, it generally follows the analysis of global data sets of Church and White (2011), discussed earlier, thereby allowing direct comparison with their results.
- Secondly, it allows the linear trend determined for the first part of the 20th century to be compared with the trend over the last five-and-a-half decades (which almost splits the records in half, as shown in table 7). If a significant change in trend has occurred in recent

[64] The Whangarei gauge has been discontinued, so figure 19 only covers the trend to 2008 given in Hannah and Bell (2012).

decades, the individual data sets are approaching a length that should enable this change in trend to be determined with some confidence, being mindful of the cautions raised in Douglas (2001) for extracting trends from records less than 60 years in length (because of the masking effect of climate variability).

Figure 19: Relative sea-level rise rates up to and including 2015 (excluding Whangarei), determined from longer sea level gauge records at the four main ports



Determined from more than 100-year gauge records at the four main ports (black circles) and inferred rates from gauge station records, used in the first half of the 1900s to set the local vertical datums, spliced with modern records (blue circles). Standard deviations of the trend are listed in the brackets. Note: mm/yr = millimetres per year; SLR = sea-level rise. Source data: Analysis up to end of 2008 from Hannah and Bell (2012) updated with seven years of MSL data to end of 2015 (Hannah, 2016); sea level data from various port companies is acknowledged.

Table 7: Updated long-term mean sea level trends at the four main ports, for the entire record and split before and after 1961

		Annual MSL time series trends (mm/yr)				
		Full dataset	Start to 1960		1961 to 2015	
Port	Record length (elapsed years)	Trend (std dev)	Years of data	Trend (std dev)	Years of data	Trend (std dev)
Auckland	1899–2015 (115)	1.60 (0.08)	60	1.76 (0.20)	55	2.34 (0.26)
Wellington	1891–2015 (116)	2.23 (0.16)	61	0.72 (0.43)	55	2.67 (0.21)
Wellington^{TC}		1.97 (0.15)			55	2.21 (0.20)
Lyttelton	1901–2015 (103)	2.12 (0.09)	48	1.33 (0.25)	55	2.54 (0.23)
Dunedin	1899–2015 (98)	1.42 (0.08)	50	0.76 (0.19)	48	1.47 (0.24)

Units for linear trend in millimetres per year together with standard deviations in parentheses. Note: MSL = mean sea level; std dev = standard deviation; Wellington^{TC} refers to the Wellington data adjusted for tectonic subsidence at an assumed rate of 1.8 mm/year since 1998 (based on continuous GPS measurements). Source: Hannah (2016)

Records from the four main port tide gauges indicate a doubling in the rate of sea-level rise around the New Zealand coastline over the last five to six decades, from an average of around 1 mm/yr earlier last century to nearly 2 mm/yr from 1961 on (table 7).

When the pre-1960 datasets are compared with the post-1960 datasets in table 7, the sea level trends at all ports for the two periods are significantly different at a 99 per cent confidence level (Hannah, 2016).

When including the results from the tectonic-adjusted Wellington^{TC} dataset, the average New Zealand relative sea-level rise for the full records from 1900–2015 is 1.78±0.21 mm/year and, since 1961, has risen to 2.14±0.47 mm/year (Hannah, 2016). These results correspond closely to, although are slightly higher than, the global-mean rates given in Church and White (2011) for 1900–2009 of 1.7±0.2 mm/year rising to 1.9±0.4 mm/yr since 1961.

Sea-level rise in New Zealand waters over the satellite era (1993–2015)

Considerably higher rises in sea level (substantially above the global mean) have occurred in the western Pacific (including New Zealand) over the satellite era than in the eastern Pacific (which has been substantially below the global mean). This is covered in more detail in appendix D. This wider Pacific pattern is mainly influenced by the 20–30 year IPO, in tandem with the El Niño–Southern Oscillation.

Based on comparative analysis of satellite altimeter measurements from 1993 to 2015 inclusive, the trend for the absolute sea-level rise in the wider New Zealand exclusive economic zone ocean waters has been 4.4±0.9 mm/yr (appendix D). This higher rate is influenced considerably by climate variability over the short 23-year satellite record, which to some extent masks the ongoing long-term trend due to climate change.

Climate variability in different regional seas also extends the length of sea level monitoring record required before acceleration of the climate change signal becomes clearly evident. At the global scale, a detectable acceleration in sea-level rise is likely to emerge from the climate system variability in the coming decade (Fasullo et al, 2016), and probably later in regional seas around the Pacific (including New Zealand), where the climate variability is more pronounced (Marcos et al, 2016).

5.3 Vertical land movement in New Zealand – adjustments for local sea-level rise

Use of guidance on New Zealand sea-level rise projections (sections 5.6–5.7) requires knowledge on why and how local sea-level rise around New Zealand is affected by vertical land movement. Of most concern is the presence of significant ongoing subsidence of the landmass, which will exacerbate the absolute ocean sea-level rise (figure 16).

Future projections of sea-level rise at some locations or regions in New Zealand may also need to factor in estimates of ongoing vertical land movement.

Increasingly, networks of continuous GPS (or cGPS) gauges, co-located near sea level gauges, are being deployed to continuously record vertical and horizontal land movement at various localities. In New Zealand, the GeoNet monitoring network[65] includes a cGPS network co-funded by Land Information New Zealand, which is primarily focused on earthquake slip monitoring and changes to the geodetic survey system.

[65] See http://info.geonet.org.nz/display/equip/New+Zealand+Continuous+GPS+Network.

Data on vertical land movement also enables post-processing of local (relative) SLR, allowing the local trend to be translated into an absolute rise for the regional ocean level, and to determine the relative contribution to the local sea-level rise. This work also contributes to the global effort to improve estimates of global and regional average SLR, with the effect of local land movement removed (Hamlington et al, 2016b).

A substantial constraint on processing historic rates of rise is the limited number of cGPS gauges at or near the coast in New Zealand. In addition, cGPS gauges were first installed locally in 2002, some more recently. In future, they will provide a good baseline for tracking vertical land movement, and at least provide an indication of regions where ongoing subsidence may need to be factored into local SLR projections.

Most cGPS stations are located inland or, if near the coast, on rocky foothills, rather than the coastal sedimentary environments that are typically present around estuaries or harbours. Some cGPS gauges are co-located near tide gauges, however, particularly near the four main ports, and in some regions general trends in land movement across the region are present.[66]

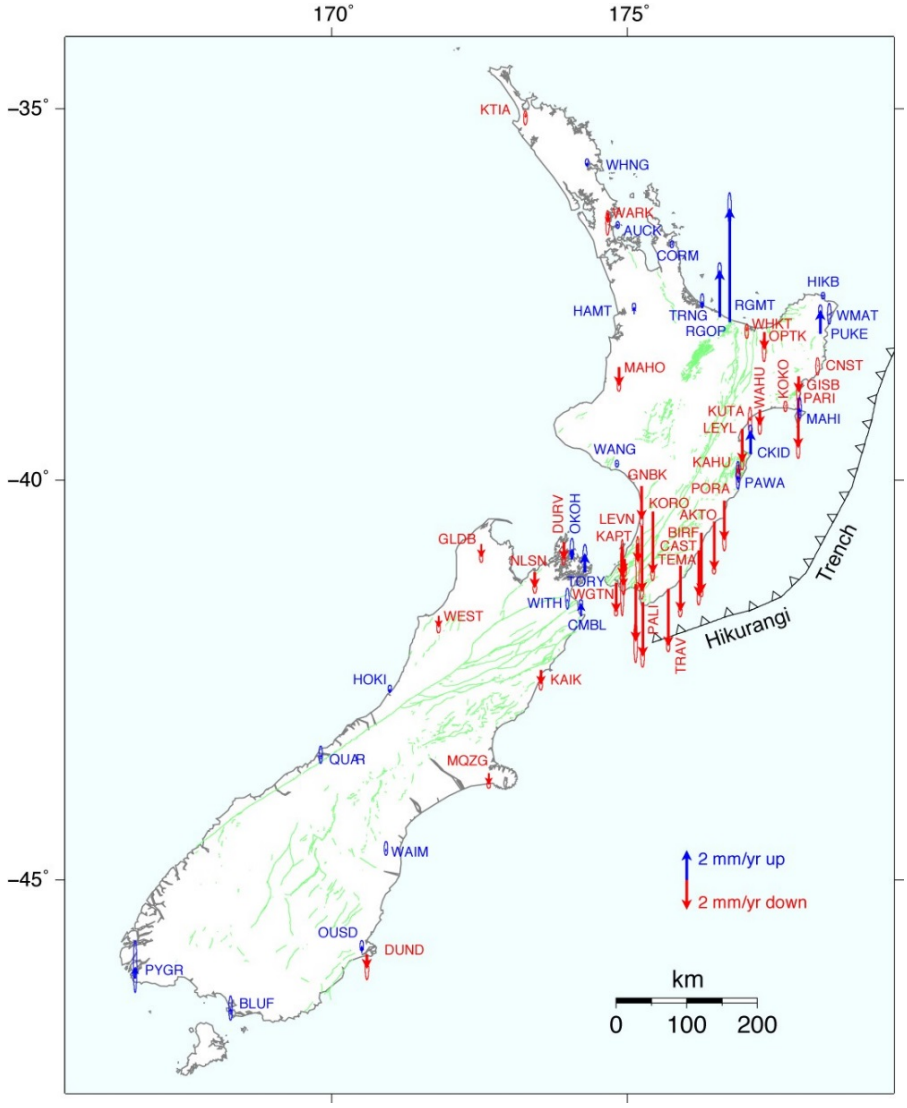
Vertical land movement for near-coastal sites was analysed by Beavan and Litchfield (2012) using cGPS record lengths of up to 10.5 years. The summary maps are shown in figures 20 and 21, and land movement rates up to mid-2012 are available in table 2 (column *gpsvel*) of Beavan and Litchfield (2012). An updated analysis has been undertaken by Denys et al (in press) and Houlié and Stern (2016).

The lower North Island is subsiding presently on average at 1–3 mm/yr due to interseismic slow-slip activity (Beavan and Litchfield, 2012; Hannah, 2016; Houlié and Stern, 2016). Whether subsidence will continue at this rate is not clear, but analysis of the trend in the Wellington tide gauge record indicates the relative SLR increased noticeably after 1998, giving rise to a higher rate of local sea-level rise in the last decade or so (Hannah, 2016).

Any significant long-term vertical land movement (beyond ±0.5 mm/yr, the accuracy of the rate at which trends can be extracted from 10-year records) should be factored into local SLR projections, especially if the land is subsiding, because this will exacerbate the local net rise in sea level that will need to be adapted to (figure 16).

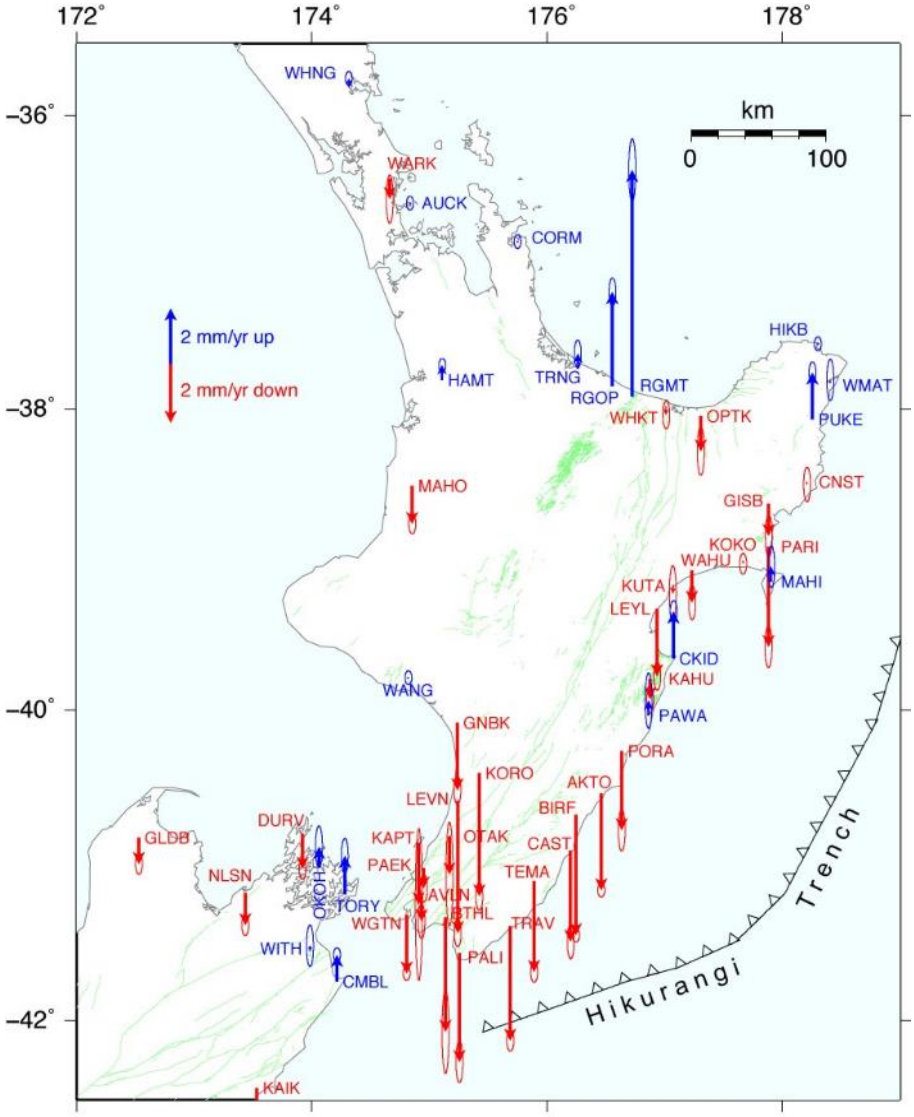
[66] Land Information New Zealand is considering extending the proximal co-location of cGPS for other longer term coastal tide gauge sites around New Zealand outside the four main ports.

Figure 20: Average vertical land movements (millimetres per year) for near-coastal continuous GPS sites across New Zealand



Blue arrows show average uplift and red arrows average subsidence over around a 10-year period.
Source: Beavan and Litchfield (2012)

Figure 21: Average vertical land movements (millimetres per year) for near-coastal continuous GPS sites across central New Zealand regions



Blue arrows show average uplift and red arrows average subsidence over around a 10-year period.
Source: Beavan and Litchfield (2012)

The other known surveyed GPS sequence for coastal land movement has been on the backshore of the southern Firth of Thames (Swales et al, 2016). Subsidence due to both tectonic and deep-sediment compaction has been occurring at an average subsidence of around 8–9 mm/yr (2007–16). This is two-to-five times higher than recorded for the same period at the nearby Tararu (Thames) tide gauge (3.6±0.7 mm/yr) and the cGPS reference station located further afield on basement rock (1.6±0.5 mm/yr). While the adjacent land on the Hauraki Plains may not be subsiding to that extent, it shows the local spatial variability that can occur across deep coastal sedimentary basins.

Moderate to strong earthquakes may also generate co-seismic land displacements or, if strong enough, surface ruptures that can instantaneously alter coastal land elevations (Beavan and Litchfield, 2012). For example, the Hawke's Bay earthquake (3 February 1931) resulted in uplift of coastal land, especially around Ahuriri Lagoon, of up to 2.7 metres, but subsidence of up to 0.7 metres along the coast from Clive to Haumoana. More recently, the north-east suburbs of Christchurch experienced subsidence from the Canterbury earthquake sequence in 2010/11 and the Kaikoura coast experienced uplift of up to 1–2 metres in the magnitude 7.8 earthquake of 14 November 2016. The Wellington coastline also shows a long geological

sequence of coastal uplift terraces from past major earthquakes, including the 1855 Wairarapa event (Beavan and Litchfield, 2012).

Future major earthquake displacements for a particular locality are deeply uncertain (both when and by how much). Unlike the ongoing sea-level rise, they could be either subsidence or uplift, other than those areas with a clear geological history of only uplift or subsidence (Beavan and Litchfield, 2012).

For foreseeable planning timeframes, this guidance does not recommend factoring in future occurrences of earthquake-generated uplift or subsidence events, due to the deep uncertainty of when and how much land elevations might change following an event.

5.4 Climate change scenarios and context for sea-level rise projections

Due to the non-linear and delayed responses of ocean and ice environments to ongoing climate change, natural variability and uncertainty on rate of global emission, it is not appropriate to extrapolate historic or even recent trends in sea-level rise observations. Instead, future projections of sea-level rise are relied on for planning and design purposes. These projections use a range of modelling and statistical approaches and can include elicitation from a wider group of experts for uncertain components, for example, polar ice sheet response.

A common approach for climate change projections is to use scenarios that are plausible descriptions of how the future might unfold in terms of interacting factors, including:

- human behaviour
- policy choices
- land-use change
- global population trends
- economic conditions
- technological advances
- international competition and cooperation (Moss et al, 2010).

From these, future emissions of greenhouse gases and other radiative forcing influencing global warming are derived. These scenarios are then used as input to climate–ocean models to derive projections of sea-level rise based on that representative scenario.

Many factors have to be taken into account when considering how future global warming will contribute to climate change and, ultimately, sea-level rise. Many different trajectories of future greenhouse gas emissions are possible, depending on the combined effect of a wide range of socio-economic influences and climate-related policies.

There are uncertainties about future socio-economic change just as there are for the evolution of a physical system, for example, climate–ocean–ice system, under a changing radiative forcing.

The goal of working with climate change scenarios is not to predict or forecast the future but to better understand how it might unfold under a consistent set of assumptions and associated uncertainties, in order to reach decisions that are robust under a wide range of possible futures (Moss et al, 2010).

It has not, in general, been possible to assign likelihoods (probabilities) to individual climate change and sea-level rise scenarios. Instead, a set of alternatives is used to span a range of possibilities. The outcomes from different forcing scenarios provide policy-makers with alternatives and a range of possible futures to consider (Collins et al, 2013; IPCC, 2013a (FAQ 12.1)). This makes climate change, particularly in the context of the long-lived inertia in sea-level rise, a different sort of decision issue; one that requires new adaptive decision-support tools to address it.

A scenario approach to sea-level rise projections also shows how other countries, such as the United States of America and United Kingdom (eg, California Coastal Commission, 2015; City and County of San Francisco Sea Level Rise Committee, 2015; Herman et al, 2015; Lowe et al, 2009), are approaching their coastal planning and risk management, rather than predetermining the future by adopting a single sea-level rise estimate (ie, there is no 'best estimate').

5.4.1 Representative concentration pathway scenarios

So that consistent climate change projections could be derived for the IPCC AR5, four representative scenarios of future radiative forcings were developed. These are called representative concentration pathways or RCPs.

Each RCP is briefly described below (with more details in appendix C).

- **RCP2.6** – peak and decline in global emissions would need to occur soon (within the next decade), rapidly reducing to zero-net or negative global emissions by the last quarter of this century (figure 22), with a probable need for sequestration of carbon from the atmosphere. World population peaks at around 9 billion later this century.
- **RCP6.0 and RCP4.5** – moderate emission-mitigation pathways, with RCP6.0 simulating initial reductions before rising again, and RCP4.5 peaking around 2050 before declining (figure 22). World population peaks at around 9–10 billion.
- **RCP8.5** – continuing high emission baseline scenario (Riahi et al, 2011), with no effective global emissions reduction. Comprises a rising radiative forcing pathway, with emissions stabilised soon after 2100 (figure 22). RCP8.5 provides a baseline pathway to compare the effectiveness of different levels of emission-reduction policies. An 'RCP8.5 world' would exhibit slow rates of economic development, slow uptake of technology. World population estimated to reach around 13 billion.

IPCC AR5 bases projections of global temperature rise and sea-level rise on simulations of various global climate–ocean modelling groups using these four RCPs as the input radiative forcing transients representing different pathways of human development.

The state of the climate in a future period, however, depends not only on the pathway of human development (eg, described by an RCP and supporting shared socio-economic pathways) but also on the response of the climate system (and its various components) to the forcing from that pathway and natural climate variability (global and regional).

Therefore, use of RCPs as inputs to climate–ocean–ice models does not mean projections should converge towards a single sea level or temperature projection trajectory for that RCP. Rather, projections encompass a range of possible outcomes for each RCP, with variability arising from use of different types of models and processes, initial start-up conditions, a range of possible response mechanisms and lags (eg, deep-ocean, glacier and ice sheet response to ongoing warming), as well as climate variability.

Percentiles are used to quantify the distribution of the various sea-level rise projections for each RCP (eg, as in IPCC AR5 projections to 2100), with the median (50th percentile) plotted as the main curve, and a range defined between specified lower and upper percentile bounds.

5.4.2 Link between global emission mitigation and sea-level rise

Emissions policy decisions made in the next few years to one-to-two decades will have a profound effect on global climate and human societies, particularly for sea-level rise, not just for this century but for the next several millennia (Clark et al, 2016). When using the range of climate change scenarios, therefore, it is important to evaluate the feasibility of significantly limiting global emissions in the next one-to-two decades, to best constrain the long-term commitment to ongoing sea-level rise.

Assessing tipping points for a long-term commitment to sea-level rise, Golledge et al (2015) concluded that substantial Antarctic ice loss can only be prevented by limiting emissions to RCP2.6 levels or below; higher emissions will considerably raise sea level for centuries. Limiting the global temperature increase to 2°C (above pre-industrial levels) by 2100 is around the threshold for tipping points for ice sheet and glacier responses (Schellnhuber et al, 2016). Levermann et al (2013) shows a steep increase in long-term commitment to SLR from temperature increases of 1.5–2°C, because the destabilisation threshold for the Greenland ice sheet is crossed.

At the Paris Conference of the Parties (COP21) round of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015, the first global agreement intended to limit global temperature rises was forged, along with collective country pledges on emission cuts that would not, at present, meet that objective (box 13).

BOX 13: PARIS AGREEMENT – DECEMBER 2015 (UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE)

The Paris Agreement (UNFCCC, 2015) was based on the most recent science. It establishes a goal of holding the global mean surface temperature rise to well below 2°C, if not 1.5°C, above pre-industrial levels. By 2012, the global mean temperature had already reached 0.85°C above pre-industrial levels.

As part of the negotiations for the 2015 Paris Agreement, 185 countries, representing 94 per cent of current global greenhouse gas emissions and 97 per cent of the global population, submitted emission pledges under Intended Nationally Determined Contributions (INDCs), mostly within a 2030 time horizon (Magnan et al, 2016).

On 5 October 2016, the threshold for signatories to the Paris Agreement was achieved, and it entered into force on 4 November 2016.

Some global climate monitoring organisations, such as Climate Action Tracker (Jeffrey et al, 2015), have projected an increase in temperature over the pre-industrial levels of around 2.7°C, with a range of uncertainty of 2.2–3.4°C by 2100, from an aggregation of these INDC pledges. The analysis assumed all submitted INDC pledges would be fully implemented and policies of similar impact would continue to be implemented after 2030. Rogelj et al (2016) projects a median warming of 2.6–3.1°C if INDC pledges are fully met, while MIT/Climate Interactive projects a higher 3.5°C if pledges are met, with deeper, earlier emission cuts needed to limit warming to no more than 2°C.

Photo credit: UNFCC

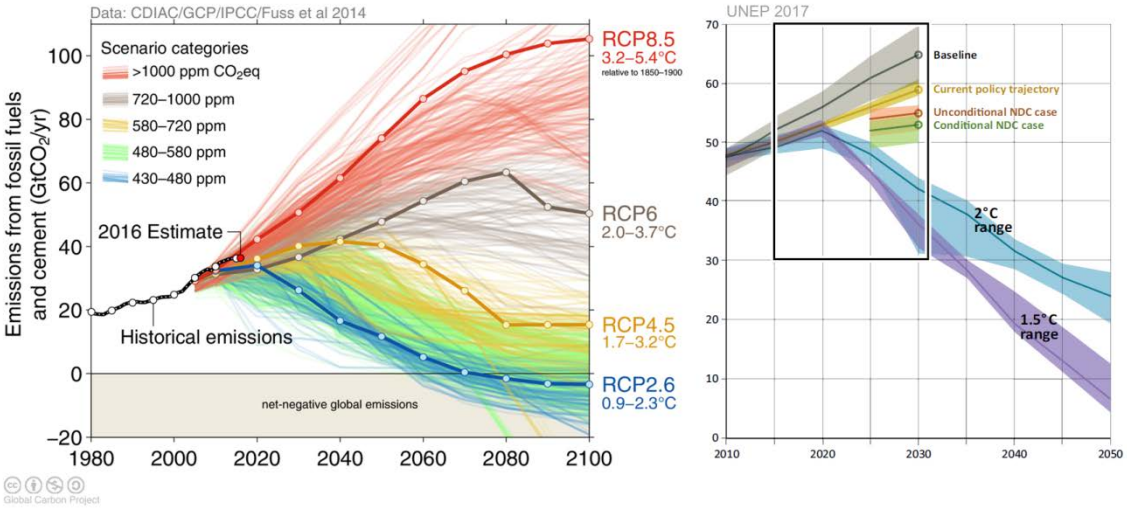
MIT/Climate Interactive: www.climateinteractive.org/programs/scoreboard/

Projected carbon dioxide emissions pathways for each RCP (and projected temperature ranges by 2100) are shown in the left panel of figure 22, along with the observed global emissions trajectory in recent years (black line), which is currently following the RCP8.5 scenario (update[67] of Fuss et al, 2014). On the right panel of figure 22, the projected temperature ranges are shown for both the aggregated pledges and the current national policies (as of December 2015) at the time of the COP21 Paris Agreement (using the analysis of Jeffrey et al, 2015).

Comparing RCP emission scenarios with the pledges and current policies in figure 22 shows that the lowest RCP2.6 pathway (a probable threshold for the onset of ice sheet instabilities) will be difficult for the global community to achieve. The uncertainty around implementation of the ambitious Paris Agreement targets, particularly beyond the 2030 target date, will also impact on its achievement (Magnan et al, 2016).

67 See www.globalcarbonproject.org/carbonbudget/index.htm.

Figure 22: Global emission scenarios and the four representative concentration pathways, with the historic emissions trajectory since 1980 (black), comparing possible temperature projections for aggregated pledges to COP21 Paris Agreement and current policies



Pledges submitted to 2015 COP21 (Paris) may avoid the high emission scenarios (red), but are still likely to generate a global temperature increase of about 2.2–3.4°C by 2100 (brown). If current emission policies continue, however, the global temperature increase could be in the range of 2.7–4.9°C (red). Temperatures are all relative to the 1850–1900 early industrial-era baseline that was used in setting global temperature goals at COP21. Note: $GtCO_2$ = gigatonnes of carbon dioxide; RCP = representative concentration pathway. Source: Fuss et al (2014); Global Carbon Project (2017);UNEP (2017)

Representative concentration pathways included in this guidance

Despite the difficult global challenge of achieving the RCP2.6 scenario (eg, Sanderson et al, 2016), this guidance includes the low-emission RCP2.6 scenario for consideration as a lower-bound surprise. At this stage, with no certainty on how successful implementation of emissions policies will be following the Paris Agreement (and beyond the 2030 milestone), sea-level rise projections covering the RCP4.5 and RCP8.5 scenarios should be considered equally in assessments, along with the range between them. An additional upper 83rd percentile RCP8.5 scenario (H^+) has been added to the suite of scenarios, to reflect a world where a higher rate of rise (eg, from faster polar ice sheet melt) may be experienced in the latter part of this century and beyond 2100. Such a scenario would primarily be used to assess greenfield developments, adaptability of major infrastructure, stress test adaptation pathways and timing of decision points.

To assess whether we are doing enough to adapt to climate change, it is important for decision-makers to understand the full range of possibilities New Zealand may face.

RCP6.0 produces similar sea-level rise projections to RCP4.5 by 2100 (within 2 centimetres for Intergovernmental Panel on Climate Change projections), so RCP6.0 has not been considered further as a scenario in this guidance. This limits the number of sea-level rise scenarios for use in risk and vulnerability assessments and adaptive management processes to four, while still ensuring they cover a range of futures that are not implausible.

5.4.3 Techniques used for future sea-level rise projections

In developing and applying guidance on sea-level rise, it is important to understand and appraise the methods used to derive future projections, to better appreciate their soundness and level of confidence in the context of uncertainties.

Uncertainty in SLR projections arises from four main sources (Lowe et al, 2009; IPCC, 2013a (FAQ 1.1)):

1 uncertainty in our understanding of the interactions within and between atmospheric, ocean and ice environments, and the level of refinement of the models to represent these complex and sometimes little-known processes and linkages

2 instabilities and thresholds for abrupt long-term changes in ice sheet response

3 uncertainty in future emission pathways, including the rate of change

4 the degree to which the effects of natural variability can be simulated for a particular future time.

There is no one single, well-accepted technique for projecting future sea-level rise. Each technique has strengths and weaknesses, with no perfect approach for anticipating future conditions, particularly with respect to quantifying the dynamics of polar ice sheet processes as they become increasingly unstable.

Confidence in projections of sea-level rise has increased since the IPCC Fourth Assessment Report (AR4) (IPCC, 2007), because of improved understanding of the contributors to sea-level change, improved datasets (especially from satellites), better agreement between model outputs and observations, and inclusion of ice sheet dynamics (IPCC, 2013b).

Four types of approaches are used when developing projections for sea-level rise and mass losses from ice stores. A summary of these approaches is categorised in table 8, with further details provided in appendix D.

Table 8: Summary of approaches to deriving future sea-level rise projections

Type	Basic approach	Examples (references)
Process-based models	Complex numerical models that simulate the dynamic processes driving the climate–ocean–ice system.	Intergovernmental Panel on Climate Change Fifth Assessment Report (Church et al, 2013a; Collins et al, 2013) Ice sheets (DeConto and Pollard, 2016)
Semi-empirical models	Based on simplified functions that estimate sea-level response to a forcing driver such as global surface temperature or radiative forcing with gain and lag parameters (calibrated using historic datasets).	Sea-level rise (SLR) overall as function of temperature: Moore et al (2013) Each contributor to SLR as separate functions of temperature: Mengel et al (2016)
Structured expert panel or elicitation	Complement process-based model approaches, where model, structural or deep uncertainty exists (eg, ice sheets) using structured expert judgement through panels or elicitation with a larger group of experts.	Bamber and Aspinall (2013) Horton et al (2014) Oppenheimer et al (2016)
Probabilistic	Uses Monte Carlo simulation technique to 'sample' many thousands of times from probability distributions for each contributing component to SLR. Distributions derived from measurements, process-based models, expert panels or science community assessments.	Jevrejeva et al (2014) Kopp et al (2014)

Sea-level rise projections, based on semi-empirical models at the time of compiling the IPCC AR5, were significantly higher than process-based model estimates, with IPCC having insufficient confidence in their reliability (Church et al, 2013a; IPCC, 2013b). Recent studies, however, with more complex and probabilistic approaches (eg, Kopp et al, 2014; Mengel et al, 2016) that individually address specific contributors to sea-level rise, for example, glaciers, ice sheets, thermal expansion, now align more closely with process-based model projections.

Expert elicitation or panel assessments in relation to ice sheet responses also have drawbacks, particularly in synthesising the wide range of estimates for contributors to sea-level rise, as discussed by Oppenheimer et al (2016) and de Vries and van der Wal (2015).

In this guidance we focus on 'process-based model' sea-level rise projections from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (Church et al, 2013a). These projections by the IPCC are only provided to the end of this century (2100), however, and only consider the 'likely range' for each representative concentration pathway (RCP) (17th to 83rd percentile of simulations), with a 33 per cent chance sea-level rise could be outside this range (Church et al, 2013b).

To supplement the IPCC projections, which only cover the next 85 years, the results of the 'probabilistic approach' of Kopp et al (2014) are also used, with projections out to 2200 (although this guidance only uses these projections to 2150). These projections also cover a wider range of percentiles for possible realisations of sea-level rise for each RCP (covering the variability within each of the contributors to SLR). The Kopp et al (2014) projections over this century reasonably closely match the IPCC projections for the median RCP8.5 scenario around the end of this century, with the RCP4.5 and RCP2.6 somewhat higher than the IPCC projections. These projections have been used internationally in adaptation assessments (eg, Boston Research Advisory Group, 2016a and 2016b).

5.5 Global climate change projections and commitment to sea-level rise

This section outlines the current global commitment to long-term sea-level rise, then covers projections for global sea-level rise up to 2120 (ie, a 100-year timeframe), with extended coverage of projections to 2150 using the results of Kopp et al (2014), based on a probabilistic approach. The offset (or departure) for the global mean projections for the seas around New Zealand, and how it was applied to global projections, is also described.

5.5.1 Long-term commitment to sea-level rise

The primary climate driver for sea-level rise is global and regional surface temperature, which is strongly influenced by greenhouse gas emissions. With the greenhouse gases currently in the atmosphere and the heat stored in the ocean, the world is already committed to further temperature increases, and an ongoing lagged response to sea-level rise, because of the inertia in polar ice sheets, which will diminish over thousands of years for any given amount of warming.

Commitment so far to long-term sea-level rise

Cumulative global emissions to date have already committed the Earth to up to an eventual 1.6–1.7 metres of global SLR relative to the present level (Clark et al, 2016; Strauss et al, 2015), if no further net global emissions occur. Due to substantial inertia in the climate–ocean–ice system, the period for this present SLR commitment to be fully realised is uncertain. What is clear is that the time to reach equilibrium extends out considerably to several centuries if severe curbs on global emissions over the next few decades limit the radiative forcing to the RCP2.6 scenario, or a less than 2°C global temperature rise, and therefore hold off instabilities developing in the polar ice sheets.

With ongoing emissions into this century, warming will continue to increase, committing to further increases in sea level well into the future, and beyond typical human planning timeframes. It is something present and future decision-makers are going to have to continually address and plan well ahead for.

5.5.2 Projections for global-mean sea-level rise

A summary of published projections for sea-level rise from the three different studies is provided below, with IPCC AR5 (Church et al, 2013a) and Mengel et al (2016) projections out to 2100, and those of Kopp et al (2014) out to 2200.

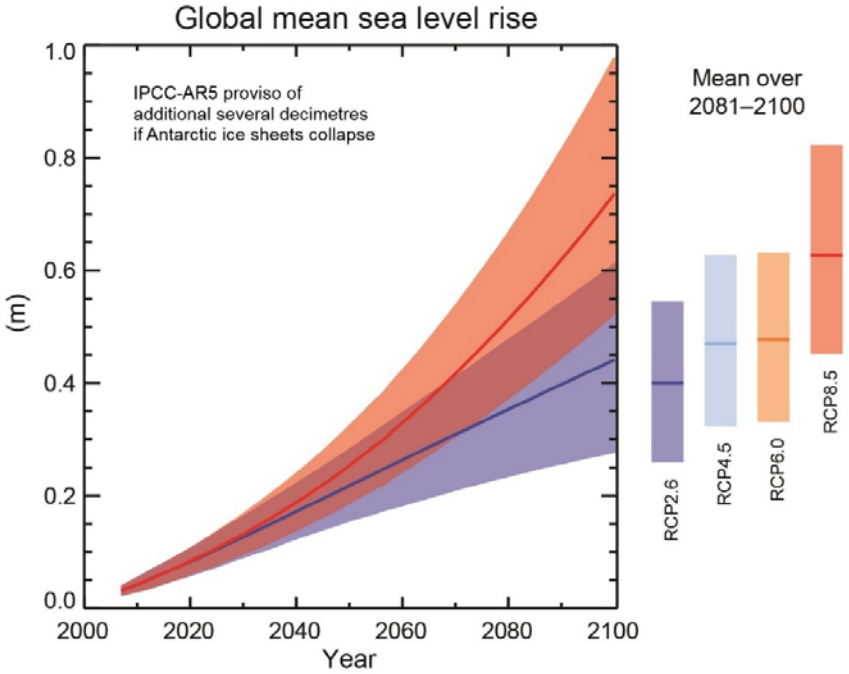
Intergovernmental Panel on Climate Change Fifth Assessment Report process-based model projections

Headline projections by the IPCC in the AR5 are summarised in the IPCC 'Summary for Policymakers' from Working Group I (IPCC, 2013b) and Synthesis Report (IPCC, 2014a).

The range of global average sea-level rise projections derived by the IPCC, based on process-based models, is shown in figure 23. This covers the likely ranges for the lowest and highest RCP2.6 and RCP8.5 scenarios up to 2100, and all four RCPs for the averaging period 2081–2100.

The zero baseline for these projections is the averaging period for MSL from 1986–2005, which is the same baseline incorporated into the guidance for sea-level rise in section 5.7.

Figure 23: Intergovernmental Panel on Climate Change Fifth Assessment Report projections of global average mean sea level (MSL) rise (metres, relative to a base MSL of 1986–2005) covering the range of scenarios from RCP2.6 to RCP8.5



The heavy line shows the median estimate for that representative concentration pathway (RCP), while the shaded area covers the 'likely range' projections for the RCP, with a 33 per cent chance sea-level rise could be outside that range. The bars on the right show the median and 'likely range' for all four RCPs averaged over the last two decades of this century (2081–2100), hence are lower than projections ending at 2100 in the main plot. Source: IPCC (2013b)

Key statements on sea-level rise in the IPCC AR5 (using the calibrated language for uncertainty and confidence in italics) include (Church et al, 2013a):

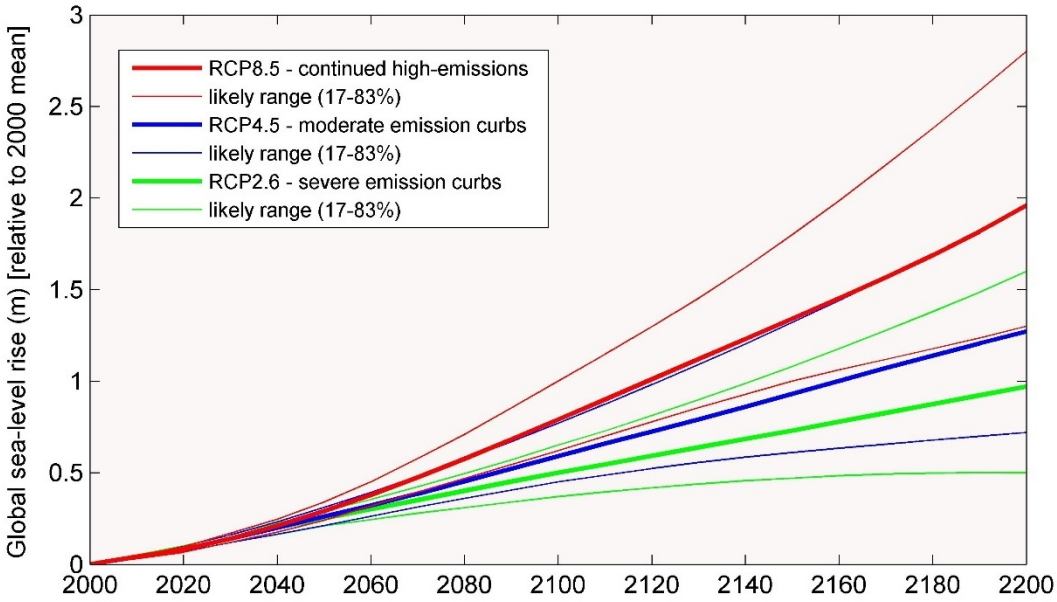
- Global mean sea-level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010.
- By 2100, sea-level rise will *likely* (ie, 66 per cent chance) be in the range 0.28–0.61 metres (RCP2.6), 0.36–0.71 metres (RCP4.5), 0.38–0.73 metres (RCP6.0) and 0.52–0.98 metres (RCP8.5), as shown in figure 23.
- Onset of the collapse of the Antarctic ice sheets could cause global MSL to rise substantially above the *likely* range (figure 23) during this century. While the contribution cannot be precisely quantified, there is *medium confidence* that it would not exceed several tenths of a metre[68] of sea-level rise by 2100.
- It is *virtually certain* that global mean sea-level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions.
- The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea-level rise of up to 7 metres, is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures.
- Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment (Church et al, 2013a). (See appendix D.)

[68] Or decimetre (one-tenth of a metre).

Recent sea-level rise projections

Using a probabilistic approach, Kopp et al (2014) produced projections out to 2200 for three RCPs (excluding RCP6.0), as shown in figure 24 (K14 projections). The approach uses thousands of projection simulations for each RCP, sampling from distributions that cover the range of variability for each contributor to SLR. This approach enables different percentile ranges to be determined (rather than just the 'likely range' used by the IPCC) to quantify the spread of possible sea-level rise within each RCP set.

Figure 24: Range of projections of global mean sea level rise to 2200 for three representative concentration pathways, relative to 2000 from Kopp et al (2014)



Heavy line = median, thin lines, the likely range (17th–83rd percentile) for projection ensembles generated by the probabilistic modelling approach.

For RCP8.5 and RCP4.5, K14 projects a median SLR of 0.79 metres and 0.59 metres by 2100 respectively (table 9), which are 5–6 centimetres higher than the IPCC projections. The median from K14 for the low-emission RCP2.6 scenario is 0.5 metres by 2100. K14 estimates show the likely range[69] of sea-level rise will be 0.62–1.0 metres for RCP8.5 and 0.45–0.77 metres for RCP4.5 scenarios by 2100, with the upper likely range for RCP8.5 similar to that of the IPCC AR5.

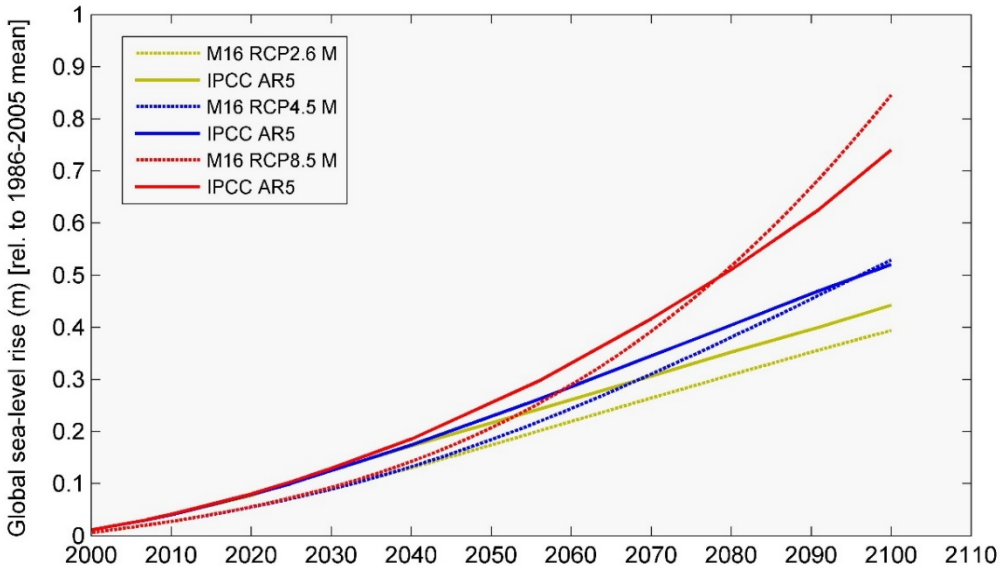
For this guidance, K14 projections out to 2150 (around a 135-year timeframe) are adopted for stress testing plans and policies and considering greenfield developments (section 5.7).

More recently, Mengel et al (2016) produced projections using an enhanced semi-empirical approach that addresses each contributor to SLR, including the latest information on ice sheets. Their model is constrained by last century's observations and the long-term equilibrium commitment to SLR. A comparison with IPCC AR5 median projections is shown in figure 25. Projections indicate a 5 per cent chance of SLR being higher than 1.3 metres for RCP8.5, and 0.77 metres for RCP4.5 by 2100, with a median SLR of 0.85 metres and 0.53 metres by 2100 respectively (as shown in table 9). Mengel et al (2016) produce a median projection for the low-emission RCP2.6 scenario of 0.4 metres by 2100, which is lower than the 0.44 metres in the IPCC AR5.

69 Between 17th–83rd percentiles of projections for that RCP, with a 33 per cent chance SLR could be outside that range.

Projections from Mengel et al (2016) were not used for generating SLR scenarios in this guidance. Rather, they show the closer agreement of enhanced semi-empirical models to process-based model results, and the potential later acceleration in SLR at the end of this century (2100) arising from ice sheet contributions, with a slower rise earlier this century than that projected by the IPCC.

Figure 25: Median projections of global mean sea level rise to 2100 for three representative concentration pathways, comparing Mengel et al (2016) or M16 and Intergovernmental Panel on Climate Change Fifth Assessment Report, relative to a 1986–2005 baseline



Note: Dashed lines are from Mengel et al (2016).

These recent semi-empirical and probabilistic SLR projections are now better constrained by past observations and align more closely (table 9) with the process-based model studies reported by the IPCC AR5. Earlier semi-empirical approaches produced higher estimates, and the IPCC concluded in the AR5 that there was no consensus on their reliability (section 13.5.2 of Church et al, 2013a).

Table 9: Projected global mean sea level rise to 2100 for RCP4.5 and RCP8.5 scenarios, comparing three sets of projections

Global MSL rise to 2100	RCP4.5 SLR (m)	RCP8.5 SLR (m)
Median (K14)*	0.59	0.79
Median (Mengel et al, 2016)**	0.53	0.85
Median (IPCC AR5)**	0.53	0.74
Likely range (K14)*	0.45–0.77	0.62–1.0
Likely range (IPCC AR5)**	0.36–0.71	0.53–0.98
5th to 95th percentile (K14)*	0.36–0.93	0.52–1.21
5th to 95th percentile (Mengel et al, 2016)**	0.37–0.77	0.57–1.31

Note: * relative to a baseline at 2000; ** relative to a baseline average from 1986–2005; IPCC AR5 = Intergovernmental Panel on Climate Change Fifth Assessment Report; K14 = Kopp et al, 2014; m = metres; MSL = mean sea level; SLR = sea-level rise.

Likely range is defined as the simulations for the representative concentration pathway that fall in 17th to 83rd percentile, as used in IPCC AR5. Source: table 1 in Kopp et al (2014) (K14); table 1 in Mengel et al (2016); table 13.5 in Church et al (2013a).

Summary of global sea-level rise projections

For projections to 2100, combining the above results indicates a likely range in SLR of around 0.5–1.0 metres, with a median of 0.74–0.85 metres for the RCP8.5 scenario; and for the RCP4.5 scenario a likely range of around 0.35–0.75 metres, with a median of 0.53–0.59 metres (table 9). RCP2.6 would generate median SLR projections of 0.4–0.5 metres by 2100.

5.5.3 Use of global projections to generate New Zealand scenarios

A scientific emphasis on the expected climate changes by 2100, which was originally driven by past computing capabilities, has perhaps created a misleading impression in the public arena that human-caused climate change is a 21st century problem and that post-2100 changes are of secondary importance, or may be reversed with emissions reductions later this century (Clark et al, 2016).

The long residence time of carbon dioxide inputs to the atmosphere, however, combined with the inertia in the climate–ocean system to these increases, implies that past, current and future emissions may commit the Earth to long-term, possibly irreversible, climate change, particularly sea-level rise (Clark et al, 2016). The long-term view (covering several centuries and beyond) shows that the next few decades offer a brief window of opportunity globally for emission reductions to minimise large-scale and potentially damaging climate change for many centuries (Clark et al, 2016; Golledge et al, 2015).

This greater level of agreement in projections across different model approaches now gives decision-makers a higher level of confidence in using sea-level rise projections. On this basis, two sets of SLR projections are combined in this guidance for RCP2.6, RCP4.5 and RCP8.5 (median trajectory) and RCP8.5 (83rd percentile) scenarios.

The base set of global SLR projections is extended to 2120, to align with the planning timeframe of at least 100 years stipulated in the New Zealand Coastal Policy Statement 2010 (NZCPS 2010) (Department of Conservation, 2010).

1 IPCC AR5 projections (Church et al, 2013a) are only available up to 2100, but were extrapolated out a further 20 years to 2120 to match the NZCPS 2010 planning timeframe. The extrapolation over the extra two decades was undertaken conservatively, maintaining the rate of rise from the previous two decades but limiting the additional acceleration in the rate post-2100, especially for the RCP4.5 and RCP2.6 scenarios.

   Note: The IPCC AR5 only provided an uncertainty range for each RCP scenario that covered the middle 66 per cent likely range from the 17th to 83rd percentile for sea-level rise; so there is a 33 per cent chance SLR could lie outside the *likely* range provided for each RCP (Church et al, 2013b).

2 Projections from Kopp et al (2014) (referred to as K14) cover timeframes out to 2200 and wider likelihood ranges from the 0.5 to 99.5 percentiles of possible SLR trajectories for *each* RCP scenario. These projections provide insight into the wide uncertainty bounds on possible ocean futures, particularly for longer timeframes.

   For development of SLR scenarios in this guidance to complement the IPCC AR5 set, an 83rd percentile RCP8.5 projection from K14 was used as an upper-range scenario out to 2150.

   The 'rate of rise' for three RCP median projections from K14 (RCP8.5, RCP4.5, RCP2.6) was used to further extend the end of the respective IPCC AR5 projections from 2120 to 2150. A similar approach was adopted in the previous guidance (Ministry for the Environment, 2008b), by recommending a rate of rise per year to be added to SLR projections beyond 2100.

Note: K14 median projections for RCP2.6 and RCP4.5 are somewhat higher than the IPCC AR5 projections around the end of this century (whereas RCP8.5 is similar), so extrapolation using just the rate of rise through to 2150 splices the K14 projections conservatively to the lower IPCC projections.

5.5.4 Can likelihoods be assigned for future sea-level rise in risk assessments?

Risk assessment practice has conventionally evaluated risk in terms of 'likelihood' and 'consequences'. No guidance is available from the peer-reviewed literature, however, on the 'overall' likelihood distribution for SLR within a given timeframe, for example, by 2100.

The main constraint is the inability to attribute specific likelihoods to each set of RCPs, because it is unclear how implementation of emission mitigation policies, land-use planning, socio-economic factors and technologies will evolve, as well as uncertainties in characterisation of physical processes and feedbacks in models.

In particular, considerable (deep) uncertainty remains in the timing and extent of the critical contribution to SLR from polar ice sheets. But what is becoming clearer from recent studies (see appendix D), especially if emissions are higher than RCP2.6, is the shift of sea-level rise projections to a more skewed tail distribution (in the upper range of possibilities) beyond 2100 that is primarily driven by the ice sheet contributions (Kopp et al, 2014; Slangen et al, 2016a).

In the near term (eg, by 2050), the projected global mean SLR range for all RCPs is relatively tight (0.2–0.4 metres), but in the latter half of this century and beyond, there is an ever-increasing range of plausible sea levels if all RCPs are considered.

Percentile distributions, including the median, for projections of possible SLR for *each* RCP scenario are available, arising from the many combinations of various contributors to SLR, climate variability and inter-model variations for the given RCP. So while a likelihood is not able to be assigned to particular SLR values, the percentile ranges in each RCP scenario set are useful inputs to adaptation planning and vulnerability or risk assessments, to test policy, planning or engineering design options including their sensitivity to sea-level rise and associated coastal hazards.

The inability to reliably assign an overall 'likelihood' distribution for global SLR in a given planning timeframe (irrespective of the RCP scenarios) is recognised in international guidance. For example, the San Francisco sea-level rise guidance (City and County of San Francisco Sea Level Rise Committee, 2015) recommends focusing risk assessments mainly on 'consequences' for each SLR scenario being assessed and evaluated before prioritising adaptation plans or asset design. In any case, sea-level rises of up to around 1 metre are 'very likely' over a planning timeframe out to the next 100–130 years – it is just a matter of when for a specific SLR.

The dynamic adaptive pathway planning approach in this guidance (chapters 8 and 9) interactively embeds the 'likelihood' or emergence aspect, where the time to reach pre-agreed trigger points (decision points) can be adjusted through regular monitoring and reviews as climate change effects unfold. This is an appropriate way of addressing future coastal vulnerability and risk management in an adaptive manner, which will enable uncertainties to be worked around, rather than adapting now to a predetermined future by selecting a best or likely estimate.

5.5.5 Offsets (departures) from the global mean projections for New Zealand seas

In developing SLR scenarios appropriate to the regional sea around New Zealand, an additional offset of a slightly higher increment of 0.05 metres by 2100 was linearly applied, on a pro rata basis with time from 2000, to the global mean projections for the RCP8.5 scenarios. A smaller offset of 0.02–0.03 metres by 2100 was added to global projections for the RCP2.6 and RCP4.5 scenarios.

These additional small offsets come from a comparison of regional SLR projections in the wider New Zealand region, with global mean projections from global IPCC AR5 modelling datasets for different climate change scenarios by Ackerley et al (2013). The offset does not include gravity changes from a redistribution of reduced polar ice mass to become melt water that disperses through the oceans.

Similar offsets of a slightly higher sea-level rise for the south-west Pacific Ocean, over and above the global mean, have been outlined in Church et al (2013a) and Reisinger et al (2014). Slangen et al (2014) found the offset for an RCP4.5 scenario was less than 10 per cent above the global mean, while projections by Kopp et al (2014) in the New Zealand regional sea show a slightly higher increase of around 10 per cent, which also included a gravitational ice sheet component.

An offset of 0.05 metres was assumed and built into the sea-level rise values provided in the previous guidance manual (Ministry for the Environment, 2008a), with recent projections and analysis (Ackerley et al, 2013) now confirming the magnitude of the offset. These New Zealand-wide projections that include this regional–sea component added to the global mean projections were then used for the guidance section (section 5.6) to generally apply to New Zealand, but may require further adjustment, up or down, for any significant local vertical land movement.

5.6 Basis for sea-level rise guidance for New Zealand

5.6.1 Approach to sea-level rise guidance

The previous guidance (Ministry for the Environment, 2008a) adopted a risk-based approach, advising users to start assessments of a range of higher sea levels at a base level of 0.5 metres and at least consider 0.8 metres by the 2090s, with an extension beyond 2100 applying a rate of 10 mm/yr.

Regional and unitary plans more recently have been adopting equivalent values of 0.7 metres and at least 1 metre, extended out by 20 years to 2115 by applying the 10 mm/yr rate, as outlined in *Coastal adaptation to climate change: Pathways to change* (Britton et al, 2011).

To satisfy the NZCPS 2010 requirement to assess hazard risks over at least 100 years (eg, 2120 and beyond), projections need to be extended using recent research and considering potentially significant polar ice sheet contributions beyond 2100. This necessitates a focus on developing and testing plans, and evaluating projects, on the basis of scenarios that cover the widening range of possible future sea levels.

Guiding principles on adopting sea-level rise scenarios

Because of the uncertainty about future changes in climate, it is necessary to examine a range of scenarios that reflect coherent and internally consistent descriptions of plausible future states. Using a range of scenarios also avoids estimates of sea-level change impacts or risks being invalidated as new sea-level projections become available (Nicholls et al, 2011a).

This is not the traditional singular "most probable future condition" approach. Comparing and selecting alternatives in a multi-scenario setting is an approach to integrating changing hazard exposure and sea-level rise uncertainty into decision-making, and represents a new challenge for planning projects or response options (US Army Corps of Engineers, 2014). The approach of comparing all alternative response options against a range of SLR scenarios avoids focusing on an option that is only best under a specific SLR scenario. This allows cases to be examined for exposure to extreme events, evaluation of response alternatives that perform robustly under most scenarios, or using adaptive pathway planning to meet objectives in a changing risk environment.

Use of a small number of scenarios is in line with international practice for coastal SLR guidance for planning and infrastructure design, for example:

- United States of America: National Research Council (2012); California Coastal Commission (2015), US Department of Transportation (2014); US Army Corps of Engineers (2014)
- United Kingdom: UK Climate Projections (2009); Lowe et al (2009); and forthcoming UKCP018 guidance
- the Netherlands: Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2014.

Four scenarios have been developed for New Zealand to cover a range of possible sea-level futures:

1 a low to eventual net-zero emission scenario (RCP2.6)

2 an intermediate-low scenario based on the RCP4.5 median projections

3 a scenario with continuing high emissions, based on the RCP8.5 median projections

4 a higher H+ scenario, taking into account possible instabilities in polar ice sheets, based on the RCP8.5 (83rd percentile) projections from Kopp et al (2014).

The latter is primarily for the purposes of stress-testing adaptation plans where the risk tolerance is low and/or future adaptation options are limited, and for setting a SLR for greenfields development where the foreseeable risk is to be avoided (Objective 5 and Policy 25(a–b), NZCPS 2010). This latter approach is similar to that used in the United Kingdom, where a more extreme H^{++} scenario was included for stress-testing adaptation plans and major coastal infrastructure (Lowe et al, 2009; Nicholls et al, 2011b). For this guidance a less extreme H^{+} scenario was selected at the upper end of the "likely range" or 83rd percentile, used by IPCC (Church et al, 2013b).

Hazard assessments, risk and vulnerability assessments and comprehensive adaptation plans (chapters 6, 8 and 9) will need to use these SLR scenarios in determining decision points for response-option pathways and understanding the sensitivity to a range of sea-level futures at a locality.

Bracketed timeframes to reach a specific increment of sea-level rise, from the earliest to latest time across the RCP2.6, RCP4.5, RCP8.5 and H^{+} scenarios, are also provided to help with the

timing of signals and triggers (decision points) and adaptation thresholds in the dynamic adaptive pathways planning process. These are used where particular SLR values or associated thresholds for frequency of inundation events have been established, based on vulnerability and risk assessments (chapters 9 and 10).

Adaptive pathways planning approaches applied at local scales, which may be significantly exposed to a low SLR trigger, will always take time to develop for communities. Therefore, transitional SLR allowances are also provided for general guidance, covering four categories of activity:

A greenfields developments or major new infrastructure

B intensification or change in land use of existing development

C existing exposed development

D low-risk non-inhabitable works and activities, particularly those with a functional need to be near the coast.

Use of single SLR values for categories C and D should be transitional, with the adaptive pathways planning approach using scenarios providing a more adaptive framework at local, regional and district scales that can accommodate surprises either way.

5.6.2 Principles behind the guidance on sea-level rise

Principles broadly considered in developing sea-level rise guidance

- Uses the best and most robust available science to determine regionally relevant sea-level rise (SLR) projections.
- No one particular or 'most likely' climate future can be determined, due to the different types of uncertainty, especially the future global emissions pathway and emergence of polar ice sheet instabilities. Therefore, planning for coastal areas needs to consider a number of scenarios to cover the range of possible futures, because no likelihood distribution can be quantified for expected SLR within a planning timeframe (other than it being a distribution skewed towards an upper-range tail, for example, figure 28).
- Decision-makers should not presume that future SLR will exactly follow any one of the SLR scenarios provided in this guidance. Instead, hazard analyses and risk and vulnerability assessments should be conducted to determine how different scenarios will affect risk, levels of service, maintenance and viability of the community before making decisions within an adaptive planning framework (see chapters 6, 8 and 9).
- Users should explicitly evaluate a range of pathways to address uncertainty, and develop options that can be evaluated for meeting particular objectives, which can be implemented in an adaptive manner at trigger points (decision points) as the future unfolds (see chapters 9 and 10).
- Flexibility is required to account for the degree of risk (likelihood of future consequences including criticality of the infrastructure and sensitivity to coastal hazards), permanence of the activity (rather than nominal design life) and adaptive capacity of the community and assets.

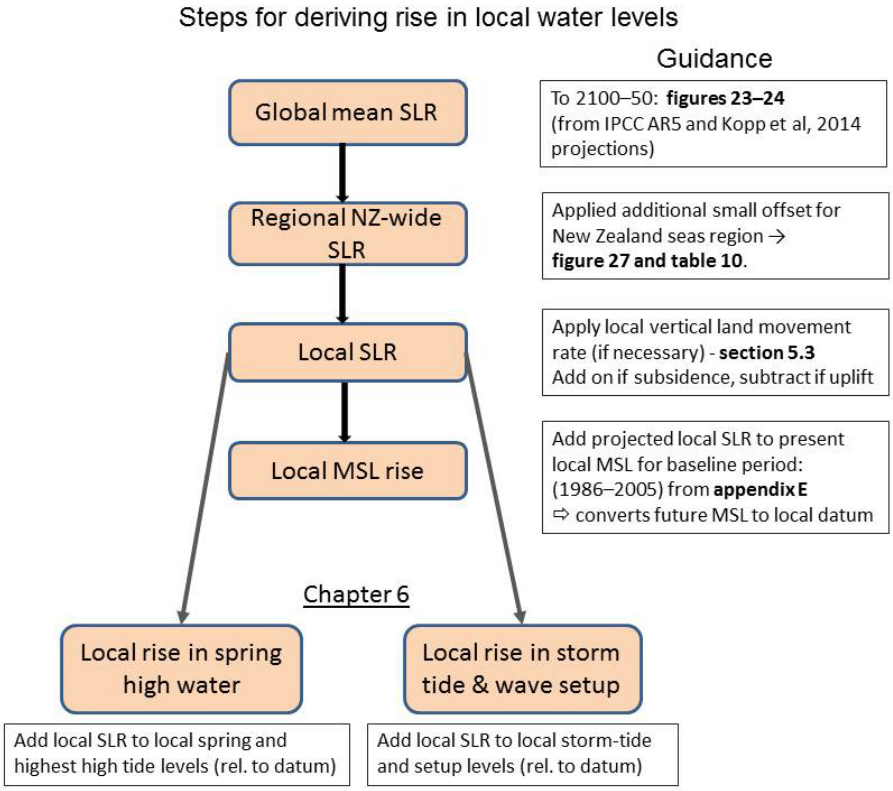
- It is prudent to stress test[70] the future climate sensitivity and adaptive capacity of the activity, policy option or land-use plan, including for existing and new development, greenfield developments and major new or upgraded infrastructure projects. Therefore, a higher H^+ scenario is provided out to 2150 based on an 83rd percentile RCP8.5 scenario. A similar approach is also used in the United Kingdom, United States of America and the Netherlands.
- Given the anticipated long life of greenfield developments and major new infrastructure, coupled with the requirement in the NZCPS 2010 to avoid future coastal hazard risks over planning timeframes beyond 100 years (including consideration of tsunami hazards), only the higher H^+ SLR scenario should be used for such new developments.
- No SLR scenario should be based on extrapolation of a past sea level trend. Such an approach assumes there will be no changes in processes that have driven the historic or even recent trend. Drivers of climate change and SLR are known to be changing, however, so extrapolation of historic trends is no longer considered appropriate or viable (eg, California Coastal Commission, 2015).
- SLR 'curves' are mathematically smooth and convenient to depict the underlying sea level trend (eg, figures 23–25). In reality, underlying climate variability at various time scales (annual to multi-decadal) will be superimposed on such curves (see figure 18). Periods of slower and faster rates of rise in sea level will continue to occur in the future.
- It is important to distinguish between global mean sea level and local (or 'relative') mean sea level, and build in appropriate differences nationally and regionally within New Zealand. The SLR scenarios provided include a small increase for the south-western Pacific region in sea level, over and above the global mean used in global projections (section 5.5.5). Users will also need to factor in a local SLR component for vertical land movement, however, especially if subsidence is occurring (see section 5.3).
- Sea level will continue to rise past 2120–50 for at least several centuries, with the rate of long-term rise and ultimate equilibrium sea level strongly dependent on reductions in global greenhouse gas emissions over the next few decades.

5.6.3 Overview of steps to derive local water levels that include sea-level rise

The steps for deriving local water levels that incorporate sea-level rise are shown in figure 26. Guidance on sea-level rise values and scenarios is provided in the section below.

[70] That is, check performance over a full range of plausible future SLR and coastal hazard scenarios for the relevant timeframe.

Figure 26: Steps to derive local water levels that include sea-level rise, starting with the global mean rise through to converting to a local datum



Note: MSL = mean sea level; SLR = sea-level rise. The local MSL rise converts the local SLR values into a level for future MSL, relative to the relevant land datum. Similarly, levels for mean high water spring and storm-tide levels (discussed in chapter 6) are usually provided relative to a vertical datum, to which the determined local SLR is added for the required planning timeframe or as a trigger value.

All SLR projections are tied back (zeroed) to an MSL baseline in the recent past. Most projections use the MSL averaged over the two-decade period 1986–2005 (mid-year 1996), including the IPCC AR5 projections (Church et al, 2013a). This provides a more stable average for a baseline covering some of the inter-annual variability, such as the two- to four-year El Niño–Southern Oscillation, rather than using a single year. The Kopp et al (2014) projections are zeroed at the year 2000 but, given the uncertainty in future projections, the difference of around 1 centimetre relative to the 1996 mid-year for IPCC projections will be negligible.

Appendix E lists the average MSL from several New Zealand gauges over the baseline period 1986–2005, relative to the local vertical datum and the New Zealand vertical datum 2016 standard (Land Information New Zealand, 2016). These values can be added to the New Zealand or local SLR scenarios or values to yield the rise in local MSL, as shown in the steps in figure 26.

5.7 Specific sea-level rise guidance for planning and design in New Zealand

Given the widening range of possible coastal futures for the latter part of this century and beyond with ongoing sea-level rise, this guidance provides more flexibility in developing adaptation plans, rather than a reliance on a single SLR value.

Components of New Zealand sea-level rise guidance

The cornerstone of the sea-level rise (SLR) guidance is the adoption of four New Zealand-wide scenarios for use in hazard, vulnerability and risk assessments and adaptation planning. These need to consider a range of futures that are not implausible. Scenario planning is also central to guidance in the United Kingdom, United States of America and the Netherlands (see above for references), rather than reliance on a single 'best estimate' SLR value that is limited to a cut-off timeframe (noting that sea level will continue rising beyond the timeframe).

Single values are, however, provided as transitional minimum SLR values for some categories of activities. These were derived using a qualitative risk-based approach in relation to the scale or type of development, given the NZCPS 2010 relates to managing the 'effects of climate change' (rather than selecting and using the 'most likely' SLR).

The adopted transitional single values for existing development or non-habitable short-lived assets maintain national consistency with SLR values currently being used by local government in New Zealand. Councils are encouraged, however, to adopt dynamic adaptive pathway planning (including testing with scenarios) for exposed communities at the local scale and council policy and planning functions and activities at the regional and district scale, using the SLR scenarios as an input to the process.

Rather than attempting to estimate likelihood of SLR for risk assessments (of which up to around 1 metre is 'virtually certain' in the foreseeable planning timeframe), table 11 provides time windows spanning years when increments of SLR could be reached in New Zealand. It starts from the earliest year (based on the 83rd percentile of a range of RCP8.5 projections, that is, RCP8.5 H+) through to the latest year it could be exceeded (based on the median low-emission RCP2.6 projection). These bracketed timeframes can be used for possible time windows for triggers (decision points) and adaptation thresholds in adaptive pathways for communities, or staging infrastructure and asset projects.

5.7.1 Suite of New Zealand sea-level rise scenarios

Users are advised to use the four sea-level rise scenarios provided in this guidance (figure 26 and table 10), when developing and testing adaptation plans and policy, and for the design and adaptive development of assets and infrastructure at the coast. They include a New Zealand-wide regional offset, with a small additional SLR above the global mean projections (section 5.5.5). Note: this same additional offset for the New Zealand-regional sea was also included in the previous guidance (Ministry for the Environment, 2008a).

The four sea-level rise scenarios are based around three RCPs (RCP2.6, RCP4.5 and RCP8.5), as discussed in section 5.4.1. Three of the scenarios are derived from the median projections of global sea-level rise for the RCPs presented by the IPCC in its Fifth Assessment Report (AR5) (Church et al, 2013a). For this guidance, these have been extended to 2120, to meet the minimum requirement of assessing risk over at least 100 years, as required by the NZCPS 2010. A further extension to 2150, using the rates of rise from Kopp et al (2014), provides a longer view over 130 years (with a gap shown in figure 27 between the two sets of projections). It is also a reminder that sea level will keep rising after 100 years, irrespective of actual future greenhouse gas emissions.

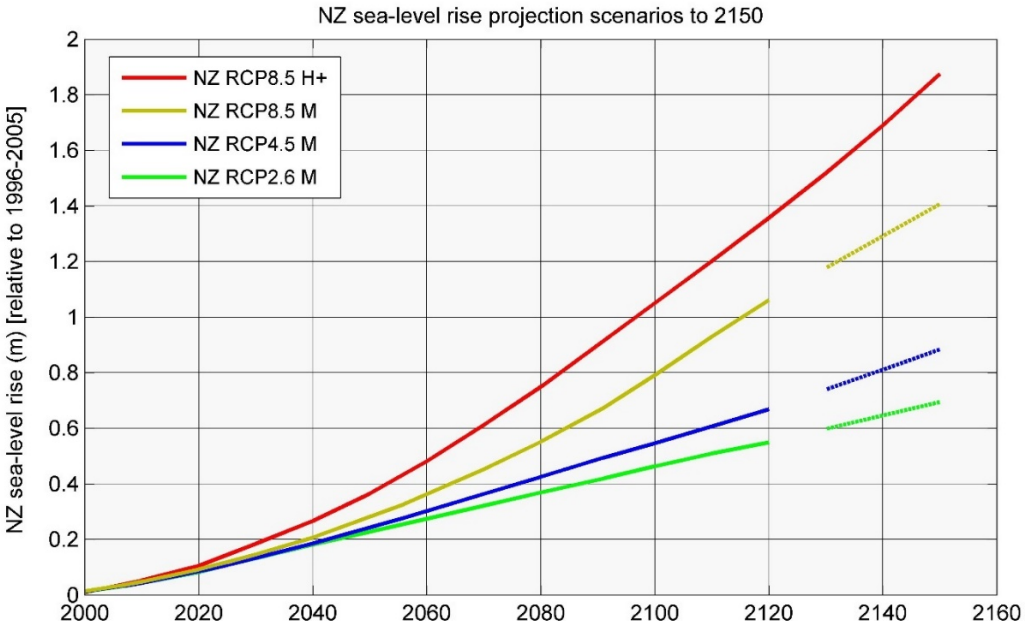
As discussed earlier in this chapter, a quantitative likelihood (or probability of occurrence) cannot be assigned to any particular scenario and, therefore, quantifying an overall likelihood distribution for sea-level rise by 2100 or 2120 is not possible (except that it will exhibit a skewed-tail distribution due to the behaviour of polar ice sheets, see figure 28). Therefore,

the three scenarios based on the median sea-level rise projections (M) projections, along with an upper-range scenario, should be used in adaptation planning assessments. It will be challenging, however, to achieve the lowest RCP2.6 M scenario as described earlier, because of the rapid and large reductions in emissions required globally.

The fourth scenario, NZ RCP8.5 H^+, is at the upper end of the 'likely range' (ie, 83rd percentile[71]) of the wide ensemble of SLR projections by Kopp et al (2014) based on RCP8.5.[72] In particular, this higher scenario reflects the possibility of future surprises towards the upper range in SLR projections of an RCP8.5 scenario. It is representative of a situation where more rapid rates of SLR could occur early next century due to dynamic ice sheet processes and instability thresholds that were not fully quantified in the IPCC AR5 projections.

New Zealand's RCP8.5 H^+ should also be used with the other median scenarios for completeness, particularly to stress-test dynamic adaptive pathways, policies and new greenfield and major infrastructure developments. Such higher-end scenarios are used in the United States of America (US Army Corps of Engineers, 2014; National Research Council, 2012; US Department of Transportation, 2014) and United Kingdom (Lowe et al, 2009) to provide checks on planning for long-lived or critical infrastructure (eg, the Thames River barrage in London); or where the risk tolerance is low or the future options for adaptation are quite limited. It also informs the decisions on avoiding risk for new developments or intensification of existing development in coastal areas.

Figure 27: Four scenarios of New Zealand-wide regional sea-level rise projections for use with this guidance, with extensions to 2150 based on Kopp et al (2014)



New Zealand scenario trajectories are out to 2120 (covering a minimum planning timeframe of at least 100 years), and the NZ H^+ scenario trajectory is out to 2150 from Kopp et al (2014) (K14). No further extrapolation of the Intergovernmental Panel on Climate Change-based scenarios beyond 2120 was possible, hence the rate of rise for K14 median projections for RCP2.6, RCP4.5 and RCP8.5 are shown as dashed lines from 2130, to provide extended projections to 2150. Note: all scenarios include a small sea-level rise (SLR) offset from the global mean SLR for the regional sea around New Zealand.

[71] Same upper percentile used by IPCC for distribution of SLR projections (Church et al, 2013b)

[72] Note: the percentiles are not to be confused with probabilities of likelihoods of that SLR scenario – rather the percentiles including the median (or 50th percentile) describe the range of SLR projections from probabilistic models or across all the model simulations for that RCP.

Table 10: Decadal increments for projections of sea-level rise (metres above 1986–2005 baseline) for the wider New Zealand region (for the four future scenarios from figure 27)

NZ SLR scenario Year	NZ RCP2.6 M (median) [m]	NZ RCP4.5 M (median) [m]	NZ RCP8.5 M (median) [m]	NZ RCP8.5 H^+ (83rd percentile) [m]
1986–2005	0	0	0	0
2020	0.08	0.08	0.09	0.11
2030	0.13	0.13	0.15	0.18
2040	0.18	0.19	0.21	0.27
2050	0.23	0.24	0.28	0.37
2060	0.27	0.30	0.36	0.48
2070	0.32	0.36	0.45	0.61
2080	0.37	0.42	0.55	0.75
2090	0.42	0.49	0.67	0.90
2100	0.46	0.55	0.79	1.05
2110	0.51	0.61	0.93	1.20
2120	0.55	0.67	1.06	1.36
2130	0.60*	0.74*	1.18*	1.52
2140	0.65*	0.81*	1.29*	1.69
2150	0.69*	0.88*	1.41*	1.88

* Extended set 2130–50 based on applying the same rate of rise of the relevant representative concentration pathway (RCP) median trajectories from Kopp et al, 2014 (K14) to the end values of the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) projections. Columns 2, 3, 4: based on IPCC AR5 (Church et al, 2013a); and column 5: New Zealand RCP8.5 H^+ scenario (83rd percentile, from Kopp et al, 2014). Note: M = median; m = metres; NZ = New Zealand; SLR = sea-level rise. To determine the local SLR, a further component for persistent vertical land movement may need to be added (subsidence) or subtracted (uplift).

5.7.2 Bracketed range of timeframes when specific sea-level rise increments would be reached

For a range of sea-level rise increments, table 11 provides a bracketed sequence of years in the future when specific SLR increments could be reached in New Zealand, starting from the earliest year (based on the RCP8.5 H^+ projection) through to the latest year it could be exceeded (using a median RCP2.6 projection).

These bracketed timeframes can be used to inform the time window for when triggers (decision points) and adaptation thresholds in adaptation plans for communities or infrastructure will occur (which may be tied to a derived SLR value as the trigger). It is important to remember, however, the (possibly considerable) lead time that will be required to implement the plan or pathway (chapter 10).

Users also need to be mindful that ongoing local or regional sea-level monitoring and regular review of adaptation plans will be required (chapter 11), as well as changes in projections in future IPCC reports or scientific publications. The outcomes of these reviews may change the bracketed time windows and require decision points for adaptive pathways to be advanced[73] or delayed.[74]

[73] If the rate of SLR is faster than projected.

[74] If SLR is slower than anticipated or considerable reductions in global emissions are achieved.

Table 11: Approximate years, from possible earliest to latest, when specific sea-level rise increments (metres above 1986–2005 baseline) could be reached for various projection scenarios of sea-level rise for the wider New Zealand region

SLR (metres)	Year achieved for RCP8.5 H^+ (83%ile)	Year achieved for RCP8.5 (median)	Year achieved for RCP4.5 (median)	Year achieved for RCP2.6 (median)
0.3	2045	2050	2060	2070
0.4	2055	2065	2075	2090
0.5	2060	2075	2090	2110
0.6	2070	2085	2110	2130
0.7	2075	2090	2125	2155
0.8	2085	2100	2140	2175
0.9	2090	2110	2155	2200
1.0	2100	2115	2170	>2200
1.2	2110	2130	2200	>2200
1.5	2130	2160	>2200	>2200
1.8	2145	2180	>2200	>2200
1.9	2150	2195	>2200	>2200

The earliest year listed is based on the RCP8.5 (83rd percentile) or H+ projection and the next three columns are based on the New Zealand median scenarios in figure 27, with the latest possible year assumed to be from a scenario following RCP2.6 (median). Note: the year for achieving the sea-level rise is listed to the nearest five-year value.

5.7.3 Minimum transitional allowances for sea-level rise

While working towards long-term adaptive planning (chapters 8–10), using the four recommended SLR scenarios for hazard, and risk and vulnerability assessments in engagement with communities, minimum transitional SLR allowances are provided for use in planning processes for four broad categories of development (table 12). An additional component may need to be applied to these SLR allowances for significant vertical land movement for some regions or local areas.

This guidance recommends categories of activities for which specific transitional SLR allowances should apply, to provide more clarity than the previous guidance (Ministry for the Environment, 2008a). SLR allowances are provided for four categories (A–D) of activities or types of development and are expressed as either scenarios or a minimum value to use (table 12).

The highest H^+ scenario should be the only scenario used for new developments eg, greenfields or major new infrastructure (category A). The use of just the H^+ scenario stems from the anticipated long life of such new developments, coupled with the requirement in the NZCPS 2010 to avoid future hazard risks (and also to consider tsunami hazards) over planning timeframes beyond 100 years (ie, 2120 onwards).

For informing where intensification of existing development is inadvisable (category B), no transitional SLR value is provided - rather the full dynamic adaptive pathways planning approach should be undertaken using all four SLR scenarios (at the scale appropriate to the proposed intensification), before further intensification occurs (to avoid compounding the future risk).

Category C generally covers existing development (and is the most challenging for adaptation), while category D applies to short-lived non-habitable assets and where consequences are low

or readily adaptable. The minimum transitional SLR values of 0.65 metres and 1 metre respectively for these latter two categories are generally applicable towards the end of the next 100 years (eg, up to 2120).

If transitional single values for SLR are used (eg, for categories C and D), hazard and risk assessments (chapters 6 and 8) should still be undertaken for a range of sea-level rise, using the scenarios (figure 27) or increments in SLR (including the transitional value) to better understand the hazard-risk profile and thresholds for a region or location.

Table 12: Minimum transitional New Zealand-wide SLR allowances and scenarios for use in planning instruments where a single value is required at local/district scale while in transition towards adaptive pathways planning using the New Zealand-wide SLR scenarios

Category	Description	Transitional response
A	Coastal subdividion, greenfield developments and major new infrastructure	Avoid hazard risk by using sea-level rise over more than 100 years and the H+ scenario
B	Changes in land use and redevelopment (intensification)	Adapt to hazards by conducting a risk assessment using the range of scenarios and using the pathways approach
C	Land-use planning controls for existing coastal development and assets planning. Use of single values at local/district scale transitional until dynamic adaptive pathways planning is undertaken	1.0 m SLR
D	Non-habitable short-lived assets with a functional need to be at the coast, and either low-consequences or readily adaptable (including services)	0.65 m SLR

Application to existing development or non-habitable assets (categories C and D)

Deriving a single value for SLR to apply nationally to existing development is difficult, given the wide range of sea-level trajectories into next century. It can lead to a rigid predetermination of the future if planning is based solely on this value. A range of risks exist for different scales of activity associated with coastal climate change impacts, and a lower SLR allowance may be appropriate for activities with a functional need to be near the coast, or short-lived non-habitable assets, where low consequences and a high degree of flexibility to adapt exists.

Transitional SLR values for categories C and D correspond to the equivalent values recommended for SLR to the 2090s from the previous Ministry for the Environment (2008a) guidance, with 1 metre SLR currently being used in a number of regional and district plans in New Zealand out to 2115. The 1 metre SLR value for coastal-hazard planning (in relation to existing development) was also supported by the Independent Peer Review Panel reviewing the Tonkin+Taylor coastal hazard assessment for Christchurch (Kenderdine et al, 2016).

The minimum SLR value (0.65 metres) for category D (non-habitable assets) aligns with the NZ RCP4.5 M scenario out to 2120. If the higher NZ RCP8.5 M scenario eventuated, the lower 0.65 metre transitional SLR (for Category D) would be reached earlier, around 2085–90 (figure 27 and table 10), but still compatible with short-lived assets.

Keeping similar transitional SLR values for this guidance also reflects the outcomes of syntheses of recent information published post-IPCC AR5 (Clark et al, 2015; Slangen et al, 2016a), which are still equivocal about the timing of additional polar ice sheet contributions to

SLR by 2100. Keeping similar values for SLR transitional values also accounts, in the interim, for the possibility of more effective global progress in reducing greenhouse gas emissions, although this would have to occur quickly in the next few decades to constrain SLR (section 5.4.2).

In the previous Ministry for the Environment (2008a) guidance, a risk-based appraisal for the particular application was recommended in selecting an appropriate single SLR value (above a minimum), rather than carrying forward a range of scenarios into hazard and risk assessments, and evaluating adaptation options which is advised in this revision. Policy 24(1) in NZCPS 2010 directs the identification of areas 'potentially affected' by coastal hazards and climate change (also in Policy 25), giving priority to areas at 'high risk of being affected'. Policy 27 focuses on existing development 'likely to be affected'. The wording implies a risk-based approach, focusing on the effects or impacts (Department of Conservation, 2017), rather than selecting the 'most likely' sea-level rise *scenario*, then applying that to hazard and risk assessments.

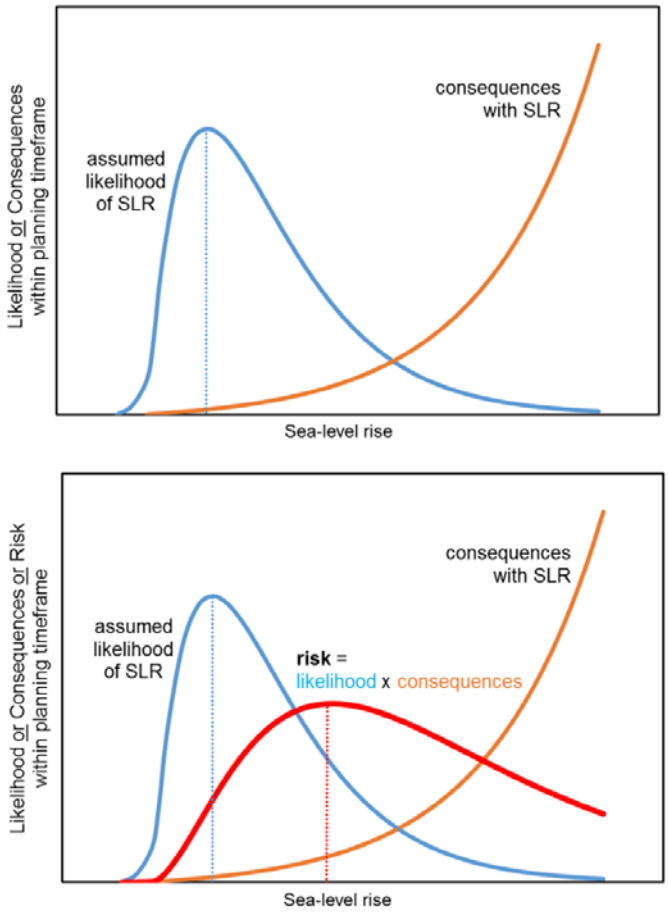
Use of a risk-based approach to selecting a sea-level rise magnitude is shown schematically in figure 28. This shows where, for a specified planning timeframe, a *generalised* probability distribution[75] of possible SLR magnitudes in a planning timeframe, peaking with a 'most likely' SLR *value*, will invariably form a skewed-tail distribution influenced by a wider range of polar ice sheet responses (Kopp et al, 2014; Jevrejeva et al, 2014; Slangen et al, 2016a).

In many areas, hazard consequences (impacts) will escalate rapidly as sea level rises above a local or regional SLR threshold for damaging or disruptive coastal hazards events (figure 28).

A generalised risk profile with SLR can be obtained by multiplying the likelihood SLR distribution curve by the consequences curve, as shown in the lower panel of figure 28. This simplified example demonstrates that, in most cases, the peak of the risk curve will coincide with an SLR higher than the 'most likely' SLR.

[75] Noting that quantifying such a distribution is not possible – only the general skewed-tail shape of the distribution (blue curve).

Figure 28: Generalised skewed-tail sea-level rise (SLR) probability distribution and a generic hazard consequences curve as a function of SLR (top)



The risk within a planning timeframe (multiplying likelihood and consequence), peaks at a higher sea-level rise (SLR) (red dotted line) than the 'most likely' SLR.

Therefore, if a single transitional SLR value is to be used and applied nationally (particularly for existing development with the risk spread across multiple regions and districts), then the value adopted needs to reflect the risk exposure from the tail of higher SLR values, where hazard consequences are considerably higher.

As a result, the continued use of 1 metre SLR in 100 years in risk assessments (equivalent to 0.8 metres by 2090s from Ministry for the Environment (2008a)) is advised as a *minimum transitional value* for existing development (category C). It reflects coastal hazard risk typically peaking above a mid-range, or the 'most likely' SLR, and positioned more towards the higher end of the SLR projection range between NZ RCP4.5 M and NZ RCP8.5 M.

The application of a sea-level rise of 1 metre over a 100-year planning timeframe for existing development is also consistent with other international coastal planning guidelines (taking into account shorter timeframes) where a single SLR value is stipulated, for example:

- Australian states that have stipulated SLR values[76] mostly have these at 0.8 metres by 2100, except Western Australia (0.9 metres by 2110) and South Australia (1.0 metre by 2100)
- United Kingdom (eg, Thames Estuary 2100 flood-risk planning based initially on 0.9 metres by 2100)

[76] New South Wales and Northern Territory currently have no SLR guideline values.

- United States of America (National Research Council, 2012) and the US Department of Transportation (2014) give a mid-estimate of 0.8 metres by 2100, and a range of 0.5 metres and 1.4 metres).

While a timeframe of up to 2120 is applied to the minimum SLR values for categories C and D (table 12), it does not necessarily mean that implementation of the plans and policies, adaptation plans or infrastructure retrofit projects using that SLR value has to be undertaken completely now; implementation can be staged or occur through a pathways approach (chapters 9 and 10). Again, this highlights the requirement to move beyond transitional single SLR values (eg, categories C and D) and to undertake dynamic adaptive pathways planning that tests options or responses against a range of future scenarios.

Application to new development or major new infrastructure (category A)

The NZCPS 2010 (Objective 5, Policy 25) treats greenfields development or change in land use differently from existing development. It has an emphasis on locating such development (including infrastructure where practicable) away from areas prone to coastal hazard risks (including from climate change) and avoiding increasing the risk (chapter 2 and appendix A; see also Department of Conservation, 2017). Therefore, given the anticipated long life of new development under Category A, combined with sea level continuing to rise for several centuries, it is recommended such new developments are tested against a higher SLR by using only the NZ RCP8.5 H^+ SLR scenario for lifetimes beyond the 100 year timeframe (ie, 2120 onwards – see table 10). This covers the higher uncertainties posed by polar ice sheet responses and the evolving understanding of the non-linear processes involved, particularly towards the latter part of this century and beyond.

The H^+ scenario for lifetimes beyond 2120 is also commensurate with the long-term commitment to 1.6–1.7 metre SLR already embedded by emissions that have occurred to date.

Further, some planning considerations of tsunami effects are directed under the NZCPS 2010, which is addressed in the Department of Conservation NZCPS 2010 implementation guidance (Department of Conservation, 2017). While it is difficult to apply land-use planning provisions for existing development to help avoid or mitigate tsunami effects (NZCPS 2010, Policy 25(f)), the opportunity exists to incorporate "all-hazards" planning elements when assessing climate change effects for new development in greenfields, which may reduce some of the future consequences from moderate to large tsunami events. Therefore, use of the H^+ SLR scenario for new developments at the coast (category A) can also reduce tsunami risk for the proposed development.

Note: for above-ground new infrastructure at the coast, this does not imply completion now to the final built level (incorporating the H^+ SLR scenario). It could be staged progressively towards that target SLR trajectory beyond 2120, provided foundations, ground treatment or other critical design features have been adequately enhanced to cope with future stages or retrofitting.

Application to intensification of existing development or change in land use (Category B)

Likewise, the NZCPS 2010 (Policy 25) requires avoidance of redevelopment (eg, intensification) or change in land use that would increase the risk of adverse effects from coastal hazards. Given the higher test of avoiding redevelopment that could increase the risk, no transitional SLR value is provided as this could create future path dependency and avoidable increase in future risk if a higher SLR occurred.

Taking into account the context of existing development (that may already be at risk), it is recommended that before intensification or change in land use occurs in low-lying coastal areas, that a full dynamic adaptive pathways planning approach is undertaken using all four

SLR scenarios, with the higher H^+ SLR scenario to stress-test the various pathways (see chapters 9 and 10).

5.8 Climate change effects on storms, winds, storm tides and waves

Besides sea-level rise, coastal and estuarine environments will also be affected by changes in weather-related coastal-hazard drivers, such as storm surges, waves, winds, and the frequency and intensity of storms. Any changes in impacts from these drivers will have implications for coastal erosion, coastal storm inundation and groundwater and drainage levels, as discussed in chapter 6.

In summary, the other effects of climate change on coastal hazards will be secondary to ongoing sea-level rise, with the next most important effect being climate change sensitivity to wave heights for the exposed open coast, where wave runup is critical to hazard trigger or adaptation threshold levels for inundation or erosion.

An analysis of trends in extreme wave heights (1 per cent annual exceedance probability (AEP)) was determined globally by Young et al (2012) from satellite altimeter data for the period 1993–2009. Globally, there appears to be a upwards trend of 1 per cent AEP values of wind speed over the ocean, but no consistent trends for 1 per cent AEP significant wave height. The statistical uncertainty associated with estimates of the extreme value wind speed and wave heights in the ocean is such that the quantitative trend values are not reliable, however. Reliable estimates of trends in observations will require a longer duration data set.

Possible future changes in storm surge and wave climate around New Zealand were investigated by NIWA from 2009–11, as part of the Wave and Storm-Surge Projections (WASP) project (Gorman and Bell, 2011; Gorman, 2016; Lane et al, 2011). It compared modelling hindcasts and future casts, using numerical models RiCOM (River and Coastal Ocean Model) for storm surge, and the Wavewatch III model for waves covering the ocean around New Zealand. A 30-year hindcast, covering the period 1970–2000, was modelled, forced by winds and atmospheric pressure from a reanalysis generated by the European Centre for Medium Range Weather Forecasts (known as the ERA40 reanalysis dataset). These data were then dynamically downscaled in the vicinity of New Zealand using a higher-resolution model.

Modelled results for waves and storm surge from the hindcast were then compared with four future scenarios that incorporate climate change using scenarios from the IPCC (2000) known as 'SRES[77] scenarios' (see appendix C), which were used in the IPCC Fourth Assessment Report (AR4) (IPCC, 2007). Three variants of the A2 SRES scenario (similar to RCP8.5) with differing initial conditions were modelled, as well as one B2 SRES scenario (above RCP6.0) to derive results for the period 2070–99. The different scenarios provide understanding of some of the internal variability likely.

[77] SRES stands for Special Report Emissions Scenarios.

5.8.1 Storm surge projections for New Zealand

The 99th percentile storm surge peaks (based on hourly results) were calculated around New Zealand for the different scenarios for 2070–99, and compared with the hindcast climate (Lane et al, 2011). Places where consistent significant changes were seen over all the emission scenarios included the:

- South Taranaki Bight, where the change in storm-surge height ranged from 5–10 per cent, or up to 0.05 metre increase in storm-surge height
- south Otago coast, where changes were around 5 per cent, or up to a 0.03 metre increase.

Other regions did not show significant consistent changes in the 99th percentile storm-surge heights over all the modelled scenarios; small increases or decreases in storm-surge height were observed.

5.8.2 Wave projections for the Pacific and New Zealand

On a global scale, Hemer et al (2013) investigated winds and significant wave height changes using 20 climate–ocean projections out to 2100, based on the SRES scenarios used for the IPCC AR4. The largest projected changes in mean annual wave heights (expressed in percentage terms) were between ±10 per cent, with the highest increases projected for the tropical Pacific and Southern Ocean (Hemer et al, 2013; Church et al, 2013a). The mean annual wave height in the Southern Ocean will increase mainly in winter months (and will be lower than at present in summer months). This will influence wave climate in waters around southern Australia and New Zealand, which are generally expected to increase slightly by 2070–2100. Off the north-east coast of the North Island, the mean annual significant wave height is expected to decrease by a few percentage points.

Based on these projections, the southern New Zealand region can generally expect only small increases in mean annual wave height (less than 2–3 per cent), with slight increases on western and southern coasts most exposed to south-westerly swell, and small decreases elsewhere. For southern New Zealand waters, the seasonal projections show a slight decrease in mean wave heights in summer, and an increase in winter, intensifying the existing inter-annual variability (Hemer et al, 2013).

When considering the hazards associated with ocean waves, the mean annual climate is of less importance than the occurrence of extremes. Changes in the 99th percentile value[78] of significant wave height were derived from the NIWA WASP project (Gorman and Bell, 2011) and updated with RCP scenarios (Gorman, 2016). Some small increases are expected on the swell-exposed west and south coasts of New Zealand, in line with the results for long-term mean values. Generally, increases of 0–5 per cent in the 99th percentile of the significant wave height would apply around New Zealand by 2070–2100.

5.8.3 Projected changes in wind speed, atmospheric pressure and storm frequency

Upper-range wind speed is important for assessing wave heights in limited wind-fetch situations in semi-enclosed harbours, sounds and estuaries. Information on changes to mean sea-level pressure, such as during low-pressure storms and depressions, is also relevant to seasonal changes in storm surges.

[78] Based on the 99th percentile of hourly projection time series; therefore, not the same as a 1 per cent AEP event, but simply a measure of the change in the upper range of wave heights.

Projected changes of atmospheric pressure and winds for New Zealand were provided in *Climate change projections for New Zealand: Atmospheric projections based on simulations undertaken for the IPCC Fifth Assessment* (Ministry for the Environment, 2016). The key projected changes in mean sea-level pressure and mean winds are shown in figures 49–53 of Ministry for the Environment (2016).

For more extreme storm systems globally, it is considered 'likely' that the global frequency of tropical cyclones will remain essentially unchanged over the 21st century, or decrease slightly (IPCC, 2013a). However, it is *likely* that maximum wind speeds and rainfall rates will increase; in other words, the tropical cyclones will likely be stronger and cause more damage when making landfall. There is *low confidence* in region-specific projections (IPCC, 2013a).

No clear picture emerges for projections of the frequency of other storm systems for New Zealand.

For extreme winds, the effect of climate change on 99th percentile wind speeds (without direction) for three time periods and four RCPs is provided in Ministry for the Environment (2016), but without a seasonal breakdown.

From the projections for most of the RCPs and time periods, the southern half of the North Island and all the South Island are shown as having stronger extreme daily winds in future. This is especially noticeable in the South Island east of the Southern Alps. The regional climate model NIWA runs was able to resolve speed-up in the lee of the mountain ranges. It shows increases of up to 10 per cent or greater in southern Marlborough and Canterbury by the end of the century under the highest RCP8.5 forcing (see figure 52, 99th percentile wind, in Ministry for the Environment, 2016). A decrease in extreme winds in the North Island from Northland to Bay of Plenty is likely, however, probably because of increasing anticyclonic conditions.

No seasonal breakdown of extremes is given, but it is expected that the higher winds in the east of the South Island will primarily result from an increased westerly pressure gradient in winter and spring.

The projected changes in storm frequency, wave heights, storm surge and winds overall for New Zealand are relatively modest or inconclusive. Nevertheless, some sensitivity testing for coastal engineering and asset projects, and at defined coastal hazard exposure areas, should be undertaken. These should consider generic likely future increases across New Zealand of 0–5 per cent for storm surge, waves and winds and, in some areas, up to 10 per cent for waves. This is particularly so for the 100-year planning timeframe out to 2120 (which is beyond the 2070–2100 projection period used in storm surge and wave projections to date).

5.9 Guidance: storm surges, waves and winds

Trends and projections of future changes in associated coastal and ocean drivers, such as wind, waves and storm surges, are not as clear and consistent as for sea-level rise, and are likely to exhibit local and regional variations. The changes in storm frequency, wave heights, storm surge and winds projected for New Zealand are relatively modest or inconclusive (section 5.8), indicating that the overall influence of these drivers on coastal risk and vulnerability will be secondary to the dominating influence of sea-level rise. Subtle changes in these coastal drivers, however, in tandem with SLR may lead to substantial changes in shoreline erosion processes, more so than coastal storm inundation (see chapter 6).

Generic guidance includes:

- consider sensitivity to storms and extreme weather events in analyses or assessments, along with the relevant SLR scenarios. Tides, storm surges and El Niño–Southern Oscillation effects on MSL variability, winds and waves, should all be considered when making infrastructure and planning decisions and determining coastal hazard exposure areas
- combine the recommended sea-level rise projections and projections for more extreme oceanographic and coastal conditions to design projects or develop land-use plans able to withstand the impacts arising from extreme events (see chapter 6 for approaches to coastal hazard assessments)
- use the best monitoring data and modelling techniques available (chapter 6) to undertake locally relevant and context-specific coastal hazard assessments.

Specifically, the following guidance is provided based on more recent IPCC AR5- and New Zealand-based studies.

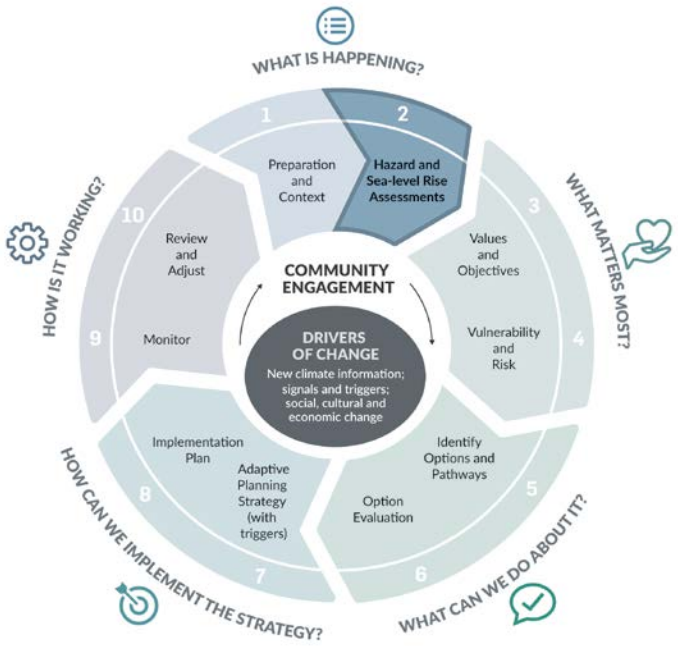
- Undertake sensitivity testing for coastal engineering projects and for defining coastal hazard exposure areas out to 2100, using:
  - a range of possible future increases across New Zealand of 0–10 per cent for storm surge out to 2100
  - a range of possible future increases across New Zealand of 0–10 per cent for extreme waves and swell out to 2100
  - changes in 99th percentile wind speeds by 2100 and incorporating these for the relevant RCP scenario from Ministry for the Environment (2016) on climate change projections, to assess waves in limited-fetch situations, such as semi-enclosed harbours, sounds, fjords and estuaries.

Beyond 2100, the SLR will tend to dominate over these secondary climate change effects on coastal areas.

6 Coastal hazards: impacts and assessments

Chapter 6	**Chapter 6 covers:** • summary of coastal hazards and coastal geomorphology • climate change impacts on coastal hazards • components and requirements for a coastal hazard assessment • the scale of hazard assessments (regional screening and detailed local studies) • consideration of freeboard (inundation) and wave setup and runup • case studies of recent hazard assessments and tools.
Step 2	**Key tasks** a. Work through checklist for setting up a coastal hazard assessment (section 6.5.1). b. Decide on the scale and scope of the assessment (screening and detailed). c. Determine data requirements (and inclusion of local knowledge). d. Determine sensitivity range for waves, storm surge and wind in hazard assessments. e. Undertake hazard assessments using sea-level rise scenarios or increments of sea-level rise and sensitivity of waves and storm surges to climate change (based on chapter 5).

Figure 29: Step 2 in the 10-step decision cycle: What is happening? – hazard and SLR assessments



6.1 Introduction

This guidance addresses two types of coastal hazard (table 13):

1 coastal inundation (compounded by flooding from rainfall, rivers and groundwater)

2 coastal erosion (beaches, estuarine shores, cliffs).

Other impacts of sea-level rise (SLR) on groundwater, drainage, saltwater intrusion and liquefaction are also discussed.

Climate change will affect these types of coastal hazard in two main ways:

- changes in storm frequency or intensity
- rising sea level.

This chapter provides information to understand and assess the different coastal hazards and their increasing physical impacts on coastal areas.

New Zealand's coastal margins are subject to natural processes that cause shoreline changes, including inundation, erosion and accretion. Erosion, inundation and groundwater issues become coastal hazards when assets or social, cultural, or environmental values are affected by these natural processes.

Climate change will not introduce any new hazards, but it will exacerbate them and in most cases increase their extent, creating new risks in coastal areas that have not previously been exposed. Among the impacts from climate change, faster sea-level rise in future is expected to be the dominant influence on coastal hazards. Sea-level rise is expected to greatly increase the frequency (and depth, and so the extent of the areas) of coastal storm inundation (Hunter, 2015; Parliamentary Commissioner for the Environment, 2014, 2015; Stephens, 2015) and the frequency and magnitude of coastal erosion, relative to the present. Sea-level rise may also affect other hazards, for example, increased groundwater affecting liquefaction susceptibility.

Policy 24 of the New Zealand Coastal Policy Statement 2010 (NZCPS 2010) directs the identification of areas in the coastal environment that are potentially affected by coastal hazards, and assessment of the associated risks over at least the next 100 years (Department of Conservation, 2010). Policies 24–25 and 27 of the NZCPS 2010 direct a risk-based approach to managing coastal hazards – this requires determination of the different likelihoods of different magnitude events and their consequences. Policy 24 prioritises identification of areas at high risk of being affected over that timeframe, which is the focus of this chapter (step 2 in the decision cycle, figure 29).

Defining areas that could potentially be affected, and those at high risk of being affected by coastal hazards, requires the involvement of a coastal hazard expert; but assessments can be supplemented by local and traditional knowledge. Understanding the uncertainties in a coastal hazard assessment, and communicating how they have been handled, is essential (Ramsay et al, 2012) for informed, risk-based decisions (chapter 8).

Uncertainty will be present in any coastal hazard assessment (chapter 4). A coastal hazard assessment should relate the hazard magnitude to its likelihood of occurring, where possible, and the source and significance of uncertainties should be identified. Sometimes statistical likelihoods cannot be assigned specifically to SLR within a planning timeframe, because of uncertainty around rates and magnitude. When this happens, an adaptive risk-based approach means including a range of future SLR scenarios in the coastal hazard assessment (chapters 5 and 8), focusing on hazard exposure. These hazard assessments then inform community engagement processes, and risk and vulnerability assessments in the next steps in the adaptation process (chapter 8).

This chapter aims to answer the following common questions when undertaking a coastal hazard assessment.

- What are the hazard sources (section 6.2)?
- What are the hazard receptors, that is, what will be impacted by the hazard (section 6.4)? What type of hazard assessment should therefore be undertaken?

- What scale of coastal hazard assessment is required (section 6.5.2)?
- Where are the vulnerable areas, and where should we focus our effort (section 6.5.3)?
- What climate change scenarios should be modelled? For example, what extreme event probabilities and what SLR scenarios (section 5.7) and future increases in waves and storm surge should be included in a coastal hazard sensitivity assessment (section 5.9)?
- What tools and models should be used (Ramsay et al, 2012) and what are the data requirements (section 6.5.5)?

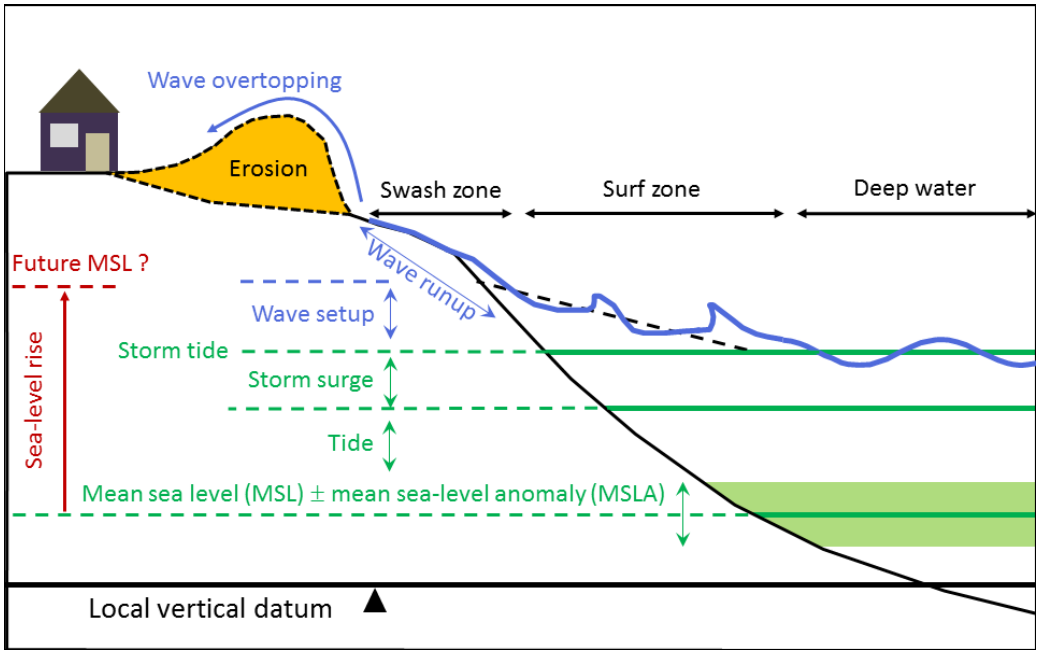
6.2 Coastal hazard sources

Several meteorological and astronomical components contribute to sea-level variability (figure 30). These coastal hazard sources can occasionally combine to cause coastal hazards that inundate low-lying coastal land, cause beach or cliff erosion, or drive changes in groundwater levels and salinity. The sources of sea-level variability, which combine to create coastal hazards, include:

- mean sea level (MSL) – the average (mean) level of the sea, relative to a vertical datum over a defined period, usually of several years
- mean sea-level anomaly (MSLA) – the variation of the non-tidal sea level about the longer term MSL on time scales ranging from a monthly basis to decades, due to climate variability. This includes the influence of El Niño–Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) patterns on sea level, winds and sea temperatures, and seasonal effects (see supplementary information sheet 3 in appendix J)
- high astronomical tides (high tide)
- storm surge – the temporary increase in sea level, induced by winds and barometric pressure associated with weather systems
- wave 'setup' and 'runup' – wave setup is the increase in mean still-water sea level at the coast, resulting from the release of wave energy in the surf zone as waves break. Wave runup is the maximum vertical extent of sporadic wave 'up-rush' of flowing water (ie, 'green water') on a beach or structure above the storm-tide level, and so is only a short-term upper-bound fluctuation in water level compared with wave setup
- wave overtopping – occurs when the wave runup exceeds the crest elevation of the beach or berm and flows over ('overtops') the top of the dune or seawall (see also figure 35)
- sea-level interaction with groundwater, including:
  - rising groundwater level
  - salinisation of groundwater
- climate change effects, including:
  - changes in the storm surge and wave climate, for example, increased storminess
  - rising sea level (incorporating both absolute and local contributors, for example, vertical land movement)
- tectonics
- tsunami.

'Storm tide' is a combination of MSL (includes datum offset) plus MSLA plus high tide plus storm surge (figure 30).

Figure 30: Coastal storm inundation and erosion sources



Graphics: NIWA

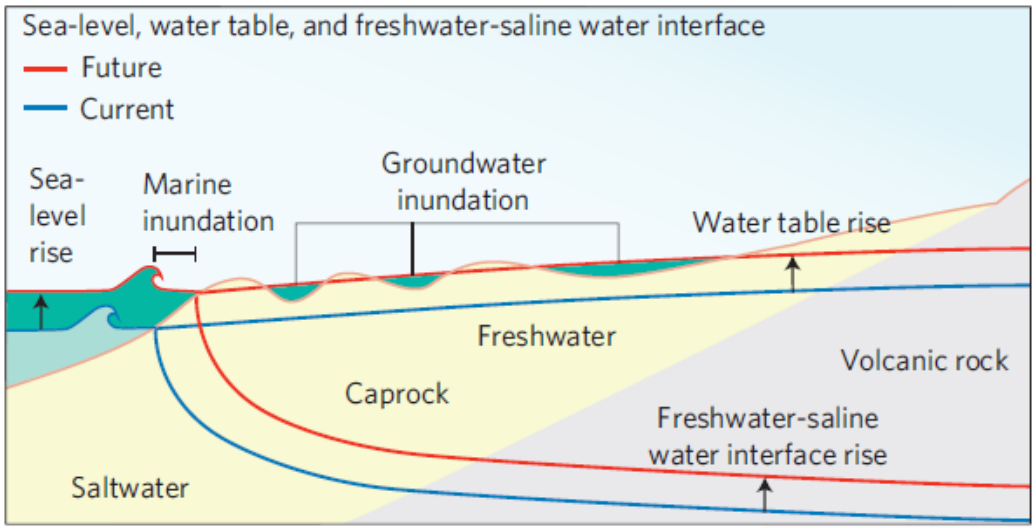
Tsunami and tectonics are not addressed in any detail in this guidance. The geological causes of tsunamis (such as earthquakes, underwater landslides and volcanic activity) will not be directly affected by climate change. The coastal effects of tsunamis will be altered somewhat by SLR, however, potentially affecting the whole area. Estuaries and harbours may also become more vulnerable to tsunami if entrance channels deepen in response to greater tidal water volumes (tidal prism) from higher sea level. The most important determiner of the magnitude of tsunami impact will continue to be the height of the tide at the time the peak tsunami wave reaches the coast, because it relates to the variables controlling water level at the coast. Ultimately, the most important variable controlling tsunami impact is the size of the tsunami, which depends on the generation mechanism and the location of the coast in relation to the tsunami source.

Unlike present-day storm-generated inundation, tsunami waves (see supplementary information sheet 13 on tsunami in appendix J) have the potential to inundate large areas of low-lying coastal plains in New Zealand. This is because of both the wave height (could be up to, or above, 10 metres for large magnitude earthquakes) and the long period of the waves (5- to 20-minute period for tsunami surges over land). Tsunami wave heights for the New Zealand coastline at 100-year and 500-year average recurrence intervals were determined in a recent revision of the tsunami hazard exposure for New Zealand (Power, 2013; and supplementary information sheet 13, appendix J). Such wave heights could be elevated further above mean high tide if the peak tsunami waves coincided with high tide. Large tsunami events are therefore likely to inundate substantial areas of coastal plains, into higher elevation zones of 5–10 metres or more, depending on the source (local or regional sources are potentially higher than remote Pacific-rim sources) and the hinterland topographic profile and overland flowpaths.

Tsunami inundation hazard modelling often uses the same model as used for dynamic coastal storm and SLR inundation modelling, and the digital elevation model is common to both. The *Tsunami Evacuation Zones: Director's Guideline for Civil Defence Emergency Management* (Ministry of Civil Defence and Emergency Management, 2016) outlines modelling approaches for deriving tsunami evacuation plans and maps.

Besides coastal inundation, low-lying coastal areas may also be vulnerable to groundwater inundation, which is localised coastal plain flooding due to a rise of the groundwater level with sea level (eg, figure 31). A rise in the groundwater level also impedes drainage of rainwater during storm events, and can contribute to and exacerbate surface or pluvial flooding. In urban Honolulu, the potential flooded area including groundwater inundation is more than twice the area of marine inundation alone. Rising groundwater levels have consequences for planners and decision-makers, and may be applicable to many low-lying coastal areas (Rotzoll and Fletcher, 2013).

Figure 31: Sea-level influence on groundwater



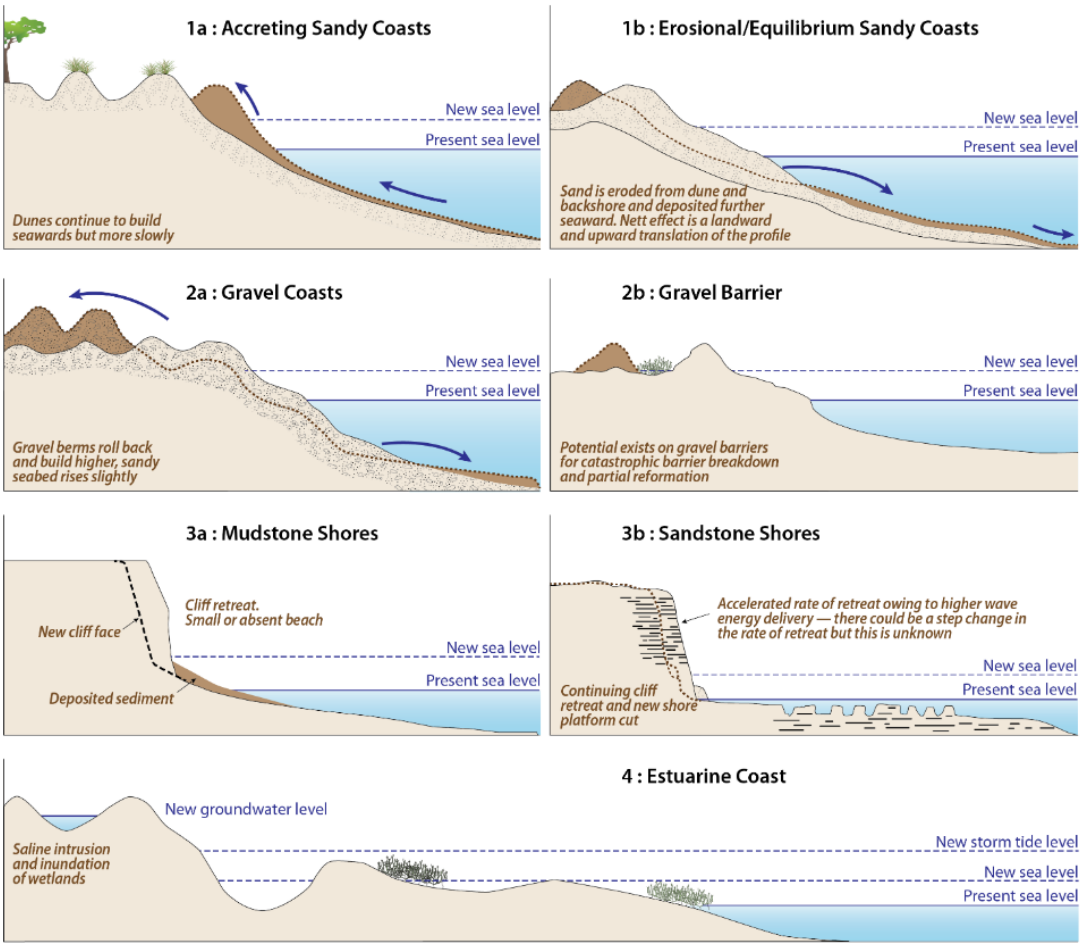
Source: Rotzoll and Fletcher (2013)

6.3 Coastal geomorphology

Climate change and sea-level rise will have an effect on coasts as they respond to changes in distribution of sediment patterns and rates of sediment transport, which in turn will affect the shape and orientation of beaches. General changes might also be expected on similar types of coastline, but the degree and extent of change will depend on local variations. Despite the great diversity of geomorphology around the New Zealand coast, the generic sensitivity of different physical coastal environments to the effects of climate change can be summarised as in figure 32.

It is important to realise that both regional and local influences, such as variability in and interrelationships between geomorphology, coastal sediments and human influences, will result in significant local deviations from the generic response, producing variations in the rates and localised implications of coastal change. How climate change may alter rates of coastal erosion or accretion is described in section 6.4.2. Coasts will, in general, be less sensitive to SLR than low-elevation sandy or gravel coastlines, but cliff erosion may be exacerbated by other climate change effects, for example, heavy rainfall and/or prolonged droughts.

Figure 32: Generalised impacts of sea-level rise on different types of coastal morphology



These schematics are only indicative, because local geomorphology, human impacts and changes to the sediment supply may produce different responses. Graphics: adapted by Max Oulton (University of Waikato) from Ministry for the Environment (2008a)

6.4 Climate change impacts

Climate change and SLR are not in themselves hazards, but they will exacerbate already occurring natural processes that drive coastal hazards.

Changes in storminess will affect the frequency and magnitude of storm-driven effects that influence coastal hazard sources such as storm surge, wave height and period and direction (sections 5.8 and 5.9), mean sea-level anomaly, and groundwater elevations.

Sea-level rise will increase the exposure of coastal land to coastal storm inundation and coastal erosion, and will raise groundwater levels near the coast. It will increase the frequency and magnitude of coastal hazards relative to those at present-day MSL. For example, the frequency of inundation above a present-day level (eg, a berm height) will markedly increase as sea level rises, and more of those events will result in deeper inundation. SLR that has already occurred since the year 1900 has led to an approximate doubling in the number of days when tides reach the mean high water perigean spring elevation as it was in 1900 (Stephens, 2015). In New Zealand, extreme sea levels that are expected to be reached or exceeded only once every 100 years (on average) or 1 per cent annual exceedance probability at present-day MSL, will occur at least once per year or more (on average) by 2050–70 – earlier for areas with smaller tide ranges (Hunter, 2015; Parliamentary Commissioner for the Environment, 2014; Stephens, 2015). Supporting information is provided in section 6.5.1.

Table 13: Example sources and actual or potential effects for different coastal hazards

Hazard	Sources	Actual or potential effects
Coastal storm inundation	Sea level (SLR, tides, storm surge) Waves River flow Rainfall Influence of ENSO and IPO Wind	Direct inundation of low-lying coastal margins, ponding and elevated groundwater levels Overtopping of dunes, coastal barrier or coastal shore-protection structures Breaching or over-washing of dunes, gravel barrier or shore-protection structures Inundation via beach access points and boat ramps Inundation via rivers and streams Backed-up stormwater systems Wave overtopping of a coastal barrier (figure 35)
Coastal erosion: beaches	Sea level (SLR, tides, storm surge) Waves (height, period, direction) Sediment supply (rainfall and/or river flow) Sediment transport (long-shore or cross-shore processes) Tidal prism in estuaries Stormwater discharge Influence of ENSO and IPO	Ongoing retreat (due to rising sea level and/or deficits in sediment budgets) Retreat (but with fluctuations in the short–medium term) Stable (but with fluctuations in the short–medium term) Fluctuations in coast position due to inlet and river mouth dynamics Increased exposure to tsunami inundation
Coastal erosion: cliffs	Sea level (SLR, tides, storm surge) Waves Rainfall Temperature Wind Influence of ENSO and IPO	Slumping and/or slippage due to: • undermining of cliff • over-steepening of cliff • removal of talus toe protection • lowering of toe beach levels • internal factors (weathering, groundwater, shrinkage)
Groundwater	SLR Rainfall	Raised groundwater level causing: • inundation due to groundwater ponding, either temporary or permanent • reduced hydraulic gradient in rivers and stormwater networks, leading to more frequent flooding, and higher flooding for prolonged periods • reduced water infiltration leading to impeded drainage of surface rain water and increased incidence of flooding • increased liquefaction potential from earthquakes. Saltwater intrusion into freshwater aquifers or streams and rivers causing: • salinisation of groundwater • change in habitat for salt-tolerant and intolerant ecology • restrictions on other uses of groundwater.

Note: ENSO = El Niño–Southern Oscillation; IPO = Inter-decadal Pacific Oscillation; SLR = sea-level rise.

6.4.1 Coastal storm inundation

Coastal storm inundation occurs when the sea encroaches onto land. In New Zealand, this usually occurs as a result of a storm coinciding with a higher than normal high tide during storm events (eg, Stephens et al, 2015b). Analyses of sea-level records in New Zealand have shown that, in sheltered areas without large waves, the most extreme sea levels occur when

several sea-level processes combine to produce high storm tides (figures 31 and 34). For most New Zealand locations, tide is the dominant component of storm tides, compounded by the MSL anomaly and storm surge. Often the storm-surge component is relatively small compared with the tide, however. There is potential for storm tides to occur that are considerably larger than those measured in existing gauge records, should an unusually high storm surge coincide with an unusually high spring tide (Stephens et al, 2015b). If recorded over a very long period of time, the maximum sea level would contain such extreme events, so they provide a useful maximum possible scenario. Although this combination could occur during any red alert tide date, they have a low chance of occurring, which is why they have not yet been observed in our sea-level records. For the four main ports, these have been kept since around 1900 (but records started much later for other locations).

There are locations in New Zealand where the highest high tides are causing inundation, even in the absence of storm surge and waves (eg, figure 34). This is a sign of things to come – as sea-level continues to rise, other locations will start to experience regular 'nuisance flooding' by high tides, and the frequency (and depth) of this flooding will rapidly accelerate (Parliamentary Commissioner for the Environment, 2015; Stephens, 2015; Sweet and Park, 2014).

Figure 33: Flooding over the Hauraki Plains, May 1938

Gale-force winds produced a large storm surge plus rain plus very high tide. Coastal stopbanks burst. Depth on land was 0.5–1.2 metres. Thousands of pounds worth of damage occurred, and 1600 hectares flooded, including houses. (Photo credit: Royal New Zealand Airforce)

Figure 34: Inundation of a Nelson car park by a high perigean spring tide, 11 March 2016

(Photo credit: Marion van Dijk)

Waves can, by themselves, overtop seawalls and dunes, causing localised inundation within several tens of metres of the coast (eg, figure 35). Wave-induced inundation (and erosion and impact damage) will be greater if coinciding with high tide, however, because the storm-tide elevation sets the base level for wave breaking and runup on the coast, and waves are depth limited so are larger near shore during high tide.

Figure 35: Inundation caused by wave overtopping of the seawall along Auckland's Tamaki Drive during ex-tropical cyclone *Ita*, 17 April 2014

(Photo credit: Victoria Lowman)

The frequency, extent and magnitude of coastal (saltwater) inundation will be substantially altered by climate change effects, and by interactions between the following sources:

- rising sea level
- long-term sea-level fluctuations
- tide range
- changes to the frequency and magnitude of storm surges
- changes in storminess and wave conditions.

An increase in MSL will be experienced as a gradual encroachment of seawater at high tides onto low-lying coastal and estuarine land, and by rising groundwater levels. If left unmanaged

by intervention of protection works, these low-lying areas will be transformed into coastal marsh and become a permanent part of the coastal or estuarine system.

Episodic inundation will still occur, caused primarily by storm events coinciding with high tides (eg, figure 33). Irrespective of any changes in the frequency or magnitude of storm surges, in storminess or wave conditions, increased MSL will increase the chance of inundation during such storm events. Specifically:

- for existing areas prone to coastal inundation, climate change means coastal inundation during storms will become more frequent, relative to the present day, given the same specific ground level or barrier height (Parliamentary Commissioner for the Environment, 2014, 2015; Stephens, 2015). Coasts with smaller tide ranges will be more frequently exposed (eg, east coast on both the North Island and South Island and Cook Strait and Wellington) than coasts with higher tide ranges (Stephens, 2015).
- the extent of the area at risk of inundation may increase relative to the present day, although this will depend on the specific site (Bell et al, 2015).
- increase in depth of inundation above the land.

Increased sea level will also progressively affect lowland rivers and streams, surface and stormwater drainage networks, and sewer and other underground utility systems in low-lying coastal areas. The performance of these systems may be compromised by a back up of flow due to increased sea level or the progressive failure of gravity drainage networks.

Where sea level is connected to terrestrial groundwater, the interaction will result in low-lying areas becoming ponds. Increased rainfall intensities may further exacerbate the problem by increasing groundwater recharge and surface flooding. Natural ecosystems in rivers and wetlands, flora along the banks, and some underground water sources will also be affected by saltwater intrusion.

Where overtopping of a coastal barrier or berm is a primary pathway for inundation, in addition to changing sea level, small changes in swell wave conditions may have a significant impact on wave setup and runup during storms. The groundwater levels along coastal margins, where presently there is a clear tidal response, will also be higher in response to SLR, which may increase inundation indirectly through the ground, or potentially add to flood volumes from wave runup and overtopping.

The potential for inundation may also be exacerbated by coastal erosion where erosion leads to a loss of either artificial shore protection structures or natural coastal defences, or where loss of the intertidal beach increases the exposure to wave breaking and runup during storm conditions (a particular issue in front of hard coastal protection structures).

While it is necessary to quantify the potential effects of climate change on inundation, the approach adopted in any area will depend on the characteristics of the area, the level of detail required for the issue under consideration, and the availability and suitability of datasets such as ground levels, topography and beach profiles. Any quantifiable assessment will need to give due consideration to the:

- availability, and length of record, of sea level, weather and wave datasets for the location or region
- uncertainties associated with the assessment methods used
- uncertainties associated with future greenhouse gas emissions and the associated magnitude of their impact on coastal hazard sources, the lack of knowledge of how some of these coastal hazard sources will change with climate change and, hence, how sensitive inundation risk is to these uncertainties

- interactions between the various coastal hazard sources, the effects of climate change on these sources and how these interactions and effects influence inundation. Coastal inundation is rarely caused by one factor alone (eg, storm surge); it is normally due to some combination of tide level, storm surge and wave conditions (and, in certain cases, exacerbated by river or land drainage and groundwater contributions). These factors are typically correlated in some way, but very rarely does an 'extreme' high tide level coincide with both high storm surge and high wave conditions (Stephens et al, 2015b). Understanding how these different sources are correlated (known as 'joint probability') is important in assessing coastal inundation (Hawkes et al, 2002; Ramsay and Stephens, 2006). Simply assuming that extreme water levels will always occur at the same time as extreme wave conditions will tend to result in overestimation of inundation risk, while assuming they are uncorrelated may result in underestimation. Joint probability modelling has been applied in New Zealand (eg, Allis et al, 2015; Stephens et al, 2015a; Stephens et al, 2016).
- dynamic nature of inundation over land, particularly the mechanism of how seawater inundates a certain area (flood pathways) and the storage potential of a flood area relative to the volume of inundating water flowing into the area. For example, in an overtopping situation, swell will generally contribute a greater volume of seawater to inundation than will shorter-period wind waves. Assuming a static or 'bathtub' approach – in which a water level is extrapolated landward until it reaches the equivalent contour height on land (based on a combination of extreme wave and water levels) – will tend to overestimate inundation (more so for wide, flat coastal plains). Where inundation is primarily a result of waves overtopping a barrier, however, this approach may underestimate inundation levels. Case Study D in section 6.6 compares the dynamic and static 'bathtub' methods for mapping coastal storm inundation over a low-lying coastal plain.

Studies undertaken for the Parliamentary Commissioner for the Environment (2015) showed that the number of coastal storm inundation events has increased since 1900, and will increase rapidly in the future if SLR accelerates (Hunter, 2015; Stephens, 2015). Areas of low-elevation land near the coast were mapped, enabling a comparison between different regions and urban areas (Bell et al, 2015).

6.4.2 Coastal erosion

Sandy coasts

Many of the world's sandy open coasts are currently eroding due to a combination of sea-level rise and a range of human effects that have reduced sediment supply to the coast (Stive, 2004). Many factors can influence erosion and accretion patterns on sandy coasts, but if other factors are held constant, an increase in the MSL at a coastline will result in horizontal retreat of the coastline and coastal erosion (Bruun, 1962). Hence, sandy open coasts in New Zealand that have been relatively stable over time are likely to erode under rising sea level, and sandy open coasts that have been eroding historically are likely to have increased erosion rates. Local erosion trends can be significantly affected by variation in sediment supply and also accommodation space. This explains why historical trends of erosion and accretion can vary over relatively small areas (eg, Piha Beach has a historical accretion trend whereas Muriwai Beach has a historical erosion trend (King et al, 2006). In some parts of New Zealand, it is possible that increased potential for erosion with sea-level rise will be balanced by the rate at which sediment is supplied. With sea-level rise, accreting open coast beaches (eg, the Manawatū coast) may continue to accrete, but probably more slowly, the rate being highly dependent on sediment supply.

In many localities, SLR will allow waves to reach the backshore and foredunes more readily (figure 36) than at present, particularly on coasts with relatively small tide ranges (irrespective of whether changes occur in wave climate or storminess). A specific SLR will be a higher proportion of a small tide range compared with a higher tide range, resulting in a higher percentage of high tides above the present MHWS mark and, hence, in more opportunities to combine with waves and storm surges (Bell, 2010).

If an increase in the frequency or heights of storm waves also occurs (section 5.8), then this combination (SLR and more frequent or higher storm waves) will have greater erosional effects on sand beach systems than at present. Where there is insufficient sediment to offset this erosion, or the width of the foreshore is constrained by hard coastal protection structures or other infrastructure that prevents the beach from accommodating the increase in water levels, the beach and dunes will experience erosion. Locations with higher dunes may suffer less retreat than locations with low dunes, although more frequent mass slumping could occur if high dunes are over-steepened. The presence or absence of dune vegetation, and vegetation type, can also influence erosion rates, since vegetation acts to trap and stabilise beach sediment.

Figure 36: Sea-level rise provides increased opportunities for waves to reach the backshore and foredunes

(Photo credits: left: R Bell; right: Waikato Regional Council)

Beaches recover naturally from storm events through across-shore sand transport exchange, also known as 'cut and fill'. Storm waves erode (cut) the upper beach and dunes, and sand is transported offshore where it is deposited in sand bars. Between storms, low-amplitude, long-period (swell) waves push the sand ashore and the beach and dunes accrete (fill). Any changes in storminess will alter natural recovery patterns. Increased storm frequency would result in more short-term erosion of sand beaches due to reduced potential for beach recovery between events, and vice versa. The potential recovery of foredunes between storms could be more limited than at present, particularly during certain ENSO and IPO phases.

Longshore sediment transport is the transportation of sediments (clay, silt, sand and shingle) along a coast at an angle to the shoreline. Longshore transport occurs when the prevailing wave or wind direction is at an angle to the shoreline, pushing sediment along the coast. On long open sections of sandy coast, longshore sediment transport rates could increase or decrease, depending on local changes in wave climate, particularly wave direction. This may change the patterns and rates of both retreat and advance of the shoreline.

Subtle changes in wave direction may also have significant effects on pocket sand beaches by moving sand from one end of the beach to the other. Such beach rotation is known to occur already in pocket beaches in eastern Australia and has been associated with different phases of ENSO (Ranasinghe et al, 2004). Beach rotation has also been shown to occur on pocket beaches in New Zealand (Bryan et al, 2013).

Spit features that are built and maintained by longshore transport are likely to be sensitive to changes in the wave climate; they will also be subject to increases in tidal flow volume passing through tidal inlets due to higher sea level.

Coastal groundwater levels may rise as a consequence of SLR, increasing the potential for beach erosion. The elevation of the groundwater level within a beach profile has a complex influence on erosion (Turner and Nielsen, 1997). Higher groundwater levels increase wave runup and the velocity of backwash, therefore increasing both runup elevations and sediment losses to the nearshore. These effects are dependent on how the beach profile adjusts to the higher groundwater level regime, however, and cannot be easily quantified.

Gravel beaches

Much of New Zealand's coast has steep beaches composed of coarse sediments (figure 37). Three types of beach are recognised: pure gravel, mixed sand and gravel, and composite, where the gravel and sand fractions are clearly distinguished across-shore (Jennings and Shulmeister, 2002). The response of these coasts to sea-level rise and changes in storminess and wave height can be difficult to predict. At least two types of response are known to occur.

Where there is a wide gravel beach or barrier that is supplied with a lot of sediment, the barrier is likely to retreat slightly and increase in height (figure 32) in response to the rising sea level, increase in wave height, or increase in the frequency or magnitude of extreme storms. Gravel barriers get rolled or pushed back during wave overtopping, regardless of how much sediment is supplied to them. The amount of sediment controls the rate of retreat. The Kaitorete barrier at the northern terminus of the Canterbury Bight or the Onoke barrier in front of Lake Onoke are both likely to respond in this way, provided no substantial changes occur in the current patterns or rates of longshore sediment transport.

Where the gravel barrier system has a net deficit in sediment supply, the barrier will experience an increased rate of retreat, or there may even be a breakdown of the gravel ridge (figure 38). Catastrophic failure of gravel barriers has been noted globally (Forbes et al, 1995), and appears to be a complex function of the driving forces (eg, sea-level rise and storms) and the mechanics of sedimentary organisation on the beach face. Many gravel beaches in New Zealand are eroding due to a combination of limited sediment supply and relative sea-level rise. Future SLR or increases in wave energy will accelerate this present-day trend. The potential for catastrophic barrier breakdown also exists, particularly where human effects have artificially reduced sediment supply to the coast, such as along the mixed sand and gravel coast north of Timaru, for example, Washdyke (Kirk, 1992).

As with sand beaches, retreat or advance of gravel beaches on long open sections of coast (eg, the Canterbury and southern Hawke's Bay coastlines) will be sensitive to changes in the rates of longshore transport of gravel caused by any long-term changes in wave direction.

Figure 37: Gravel barriers will tend to retreat, but where there is sufficient gravel, the barrier will increase in height

Source: Ministry for the Environment (2008a)

Figure 38: Wash out of a gravel barrier on the west coast of the South Island

The wash out during a storm in 2006 has significantly increased the risk of inundation due to wave runup and overtopping to the properties that back the beach. Source: Ministry for the Environment (2008a)

Cliffs

The effects of climate change on cliffs depend on the resistance of the rocks the cliffs are composed of, the water depth at the cliff toe and the morphology of any beaches or rock shore platforms in front of the cliffs (figure 39). Cliff erosion is a one-way process, and erosion rates will generally increase under SLR.

The future rate of erosion of soft-rock coasts (eg, clays and soft mudstones) can be estimated on the basis of the observed historical erosion rate and the rate of SLR (Walkden and Dickson, 2008). This method assumes a small (or absent) beach, and may be applicable to many of the soft mudstone and limestone coasts around New Zealand. As a result, as with open stretches of sand and gravel coast, rates of soft-rock cliff erosion will be sensitive to changes in the rates of longshore sediment transport that could potentially cause beaches in front of cliffs to accrete (thereby protecting cliffs) or erode. It has been shown that on some soft-rock coasts, cliff erosion rates can actually decrease under SLR if beaches build up and protect the cliffs (Dickson et al, 2007). In general, however, rates of erosion are expected to increase under SLR. Erosion rates will also increase if there is an increase in storm frequency delivering wave forces that more frequently exceed rock resistance.

Some of New Zealand's cliffs are composed of sandstones with intercalated mudstones (eg, Auckland's eastern coastline). Most of these cliffs are fronted by a gently sloping shore platform, some of which have a steep seaward edge. Erosion rates are likely to increase on these coasts under SLR, because deeper water on the platform will result in reduced nearshore wave dissipation and likely higher wave impact pressures on the cliffs. Any increase in storm

frequency will also drive high erosion rates. This process is non-linear, however, and it is not currently possible to estimate how much greater erosion rates will be at the cliff toe.
The whole cliff is subject to sub-aerial weathering and erosion, which is partly why coastal cliff retreat it is a non-linear process only partially related to wave activity. The cliff top will be sensitive to changes in drainage and moisture processes, such as extremes of drought and heavy rainfall.

Hard-rock cliffs (including many volcanic rocks) erode very slowly and episodically. In general, erosion rates are not expected to dramatically increase with SLR. Recent high storm impacts in the United Kingdom on relatively hard-rock coasts resulted in surprisingly high erosion rates, however (Earlie et al, 2015). Hence, increased storminess is likely to increase the frequency of episodic erosion events on hard-rock coasts.

For alluvial (unconsolidated) cliffs fronted by a gravel barrier beach at their base, such as found along the South Canterbury and North Otago coastlines, changes in the rate of retreat of the cliff will be linked to changes of the gravel beach in front of the cliffs. If the beach volume decreases, erosion rates are likely to increase.

Figure 39: Cliffs will tend to retreat, but the rate of retreat will depend on their geological characteristics

Source: Ministry for the Environment (2008a)

Estuarine coasts

The effects of SLR on estuarine erosion will depend on a complex interrelationship between the topography of the estuary, the increase in tidal prism volume (ie, the amount of water that flows in and out of an estuary during each tide), the estuary's sediment storage, river and open coast inputs of sediment, and the erosion of adjacent beaches (figure 40).

Sedimentation rates in most North Island estuaries have been 1–5 mm/yr to date, keeping up with the present rise in sea level (Rouse et al, 2016). Eventually, however, future increase in SLR is likely to exceed sedimentation. This may occur more quickly in urban areas, where catchments are developed and restrict sediment supply.

Figure 40: Retreat of estuarine shorelines will be highly variable

Source: Ministry for the Environment (2008a)

Estuary and harbour shorelines will retreat as a result of both inundation and erosion, but the rate and extent of retreat will be highly variable in any estuary. In general, estuary systems have a low-energy wave climate and limited exposure time (around high tide) for waves to develop and erode the shoreline. Raised water levels will permit larger waves on high tides to reach the estuary shoreline, however, potentially increasing the rate of erosion. Once erosion or loss of land occurs, recovery – if it occurs – will be a much slower process than on open coasts. Again, estuaries and harbours with a comparably smaller tide range will be more vulnerable for a given SLR (eg, most of the east coast and Wellington–Porirua area). Along low-lying areas bordering estuaries, erosion may be relatively rapid, owing to regular inundation and leading to permanent, high-tide inundation of areas that presently may experience only episodic inundation.

Where the landward retreat of the high-tide mark is constrained due to morphology, geology (eg, rock outcrop) or shore protection structures, intertidal areas and their associated ecosystems may be reduced and potentially 'squeezed out'.

Despite the possible partial compensating effect of sedimentation, SLR is likely to cause an increase in the amount of water that flows in and out of estuaries during each tide (the 'tidal prism'). Climate change may also result in larger increases in freshwater flow into estuaries during heavier rainfall events. Changes in increased flow volumes may be quite significant given the shallowness of many of New Zealand's estuaries; they will correspond to increases in tidal velocities and scour in the main channels and, particularly, at tidal entrances. It is at river, harbour and estuary mouths and inlets that coastal changes tend to be the most dynamic, particularly those associated with a spit morphology. The influences of such inlets can extend for several kilometres along the open coast adjacent to the mouth, depending on the size of the inlet. The dynamics of coastal, estuarine and river processes and multi-year cycles of sand exchange between the estuary, ebb and/or flood deltas and the adjacent coastline are complex. As a result, understanding how individual inlet systems may respond to climate change effects is complex.

6.4.3 Sea-level rise effects on groundwater levels and salinity

Groundwater levels

Sea-level rise has the potential to increase hydraulically linked groundwater regimes in coastal areas, the effect of which generally diminishes with increasing distance from the coast or tidally affected inland water courses. Resulting groundwater effects may be modelled as an additive groundwater model applied to an existing groundwater model.

SLR is likely to affect areas where groundwater dynamics are tidally influenced and increase the extent of this influence in coastal groundwater regimes. It also has the potential to raise

water levels in rivers and open water courses that exit at the coast, with additive groundwater effects extending beyond the current inland extent of tidal influence.

In coastal areas where tidal components *are* measureable in a groundwater regime, assumed sea-level rise may be added to estimate future groundwater levels (in the absence of more comprehensive hydrogeological modelling).

In coastal areas where tidal components *are not* currently measureable in a groundwater regime, it is recommended an allowance is made for increased extents of tidal influence. In the absence of hydrogeological modelling, the proportion of assumed sea-level rise used to calculate additive groundwater in these locations may be determined by reviewing tidal influences on groundwater regimes in similar geological settings. Relationships describing the diminishing effects of sea level on groundwater are best understood by comparing continuous electronic monitoring data of groundwater and nearby sea level over a number of tidal cycles, with suitable allowance for seasonal groundwater variations (Ministry for the Environment, 2008b, 2008c).

Drainage

SLR potentially has the following effects on drainage (Ministry for the Environment, 2008b, 2008c).

- Elevated sea level due to climate change will reduce the hydraulic gradient of drainage systems, causing higher flooding for prolonged periods. Current flood levels will occur more frequently as a result. This will be further exacerbated by increased rainfall intensity for extreme events due to climate change.
- Elevated groundwater conditions in low-lying areas may reduce infiltration and will cause more runoff resulting in increased flooding in areas prone to flooding.
- Intermittently closing and opening lakes and lagoons (eg, coastal lakes, river lagoon mouths and hāpua) that are artificially managed (opened) for (usually) flood management purposes will become physically more difficult to mechanically open (eg, Te Waihora/Lake Ellesmere, Wainono Lagoon and Wairewa/Lake Forsyth (managed by Christchurch City Council).
- Stormwater infiltration devices may be compromised in their performance due to higher inflows and elevated groundwater levels. As an adaptation, it may be practical to install more sub-surface drainage to deal with increases in groundwater level – or toe drains on the habitable side of stopbanks.
- Stormwater networks that are more regularly submerged by natural groundwater levels will leak, which will result in higher volumes of groundwater entering these networks. The consequence will be reduced capacity of these systems for flood events and/or reducing the capacity of pumped stormwater systems.
- Stormwater networks that become increasingly submerged by groundwater will become more difficult to service or replace.
- Many stormwater systems in New Zealand were designed before climate change was considered and may fail from the additional pressure SLR will exert, due to their age, quality and capacity.

Saltwater intrusion

Saltwater intrusion is the movement of saltwater into freshwater aquifers or hydraulically linked waterways and streams. Saltwater intrusion has the potential to change coastal and

estuarine ecosystems at the saltwater interface and make water sourced from nearby coastal freshwater aquifers and surface water unfit for use. One example (in surface water) occurred with the construction of the Woolston Cut in the Heathcote River in Christchurch, where trees died along the river bank from the salinity changes in the water. This, along with burrowing crabs, caused the banks to become unstable (Watts, 2011).

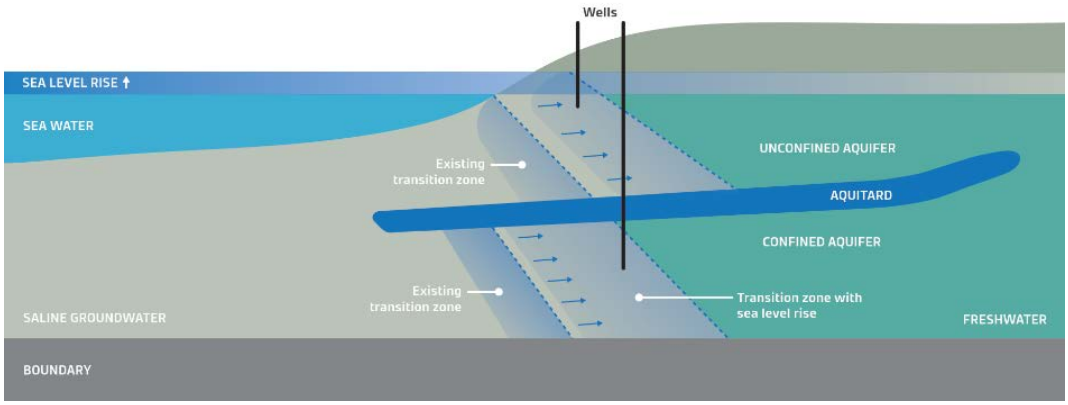
Coastal aquifers generally recharge from inland areas where groundwater levels are typically highest, to coastal discharge areas where groundwater levels are lowest. Freshwater is less dense and tends to remain above saline groundwater, separated conceptually in figure 41 by a transition zone. Salinity levels vary across the transition zone and may be represented by contours commonly inferred from measurements of either total dissolved solids concentration or chloride concentration in water sampled from observation wells (Barlow, 2003).

Historical rising and falling of sea level has resulted in the repeated advance and retreat of the saltwater interface (Meisler et al, 1984). Higher sea level generally results in the inland translation of coastal transition zones, as indicated conceptually in figure 41, although the magnitude and extent of the translation can vary significantly depending on local hydrogeological conditions.

Similarly, transition zones in coastal streams, and waterways separating freshwater discharge and coastal seawater, are generally expected to move inland in response to sea-level rise (Werner and Simmons, 2009).

Shorter term fluctuations in the transition zone bounds and gradients can also occur due to changes in the amount of freshwater flowing through the aquifer, tidal fluctuations and groundwater extraction (Werner and Simmons, 2009). Caution may be required when pumping groundwater from aquifers near the coast.

Figure 41: Higher sea level resulting in inland translation of transition zone



Graphics: Peter Quilter, Tonkin+Taylor

Liquefaction

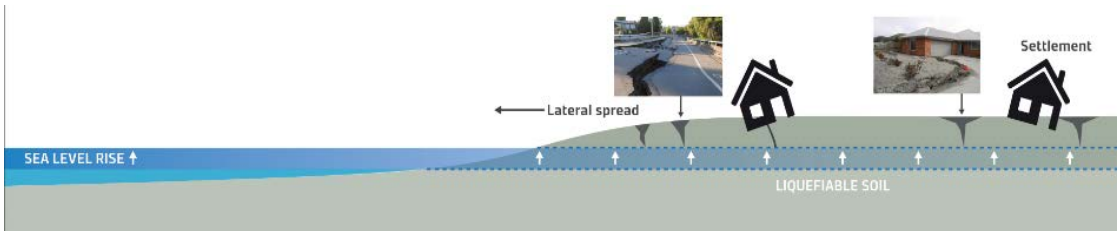
Liquefaction of soil comprising sand or silty sand can occur in response to earthquake shaking, resulting in significant and rapid loss of strength until the elevated water pressures generated by the shaking subside (New Zealand Geotechnical Society and Ministry of Business, Innovation and Employment, 2016).

Soil needs to be saturated for it to liquefy, and full saturation generally occurs in the soils located beneath groundwater level. The depth to groundwater primarily dictates the non-liquefying thickness of surface material. Ishihara (1985) indicates the thickness of surface non-liquefying material as having a profound influence on the likelihood of liquefaction-induced land damage and building damage.

Using Christchurch as a case study, Quilter (2015) showed how increases in sea level have the potential to increase groundwater levels in coastal plains and reclaimed areas with soils susceptible to liquefaction, increasing the consequences to the built environment of future earthquake events (figure 42).

Liquefaction analyses should reflect potential changes to groundwater resulting from sea-level rise. Planning decisions should account for increased vulnerability to liquefaction land damage within sustainable planning horizons.

Figure 42: Higher groundwater level in liquefiable soil due to sea-level rise, resulting in increased liquefaction land damage



Graphics: Peter Quilter, Tonkin+Taylor

6.4.4 Multiple coastal hazards

Coastal storm inundation, coastal erosion and groundwater impacts may occur individually, but some areas are likely to experience more than one of these hazards at the same time, particularly as sea level rises. Many of New Zealand's towns and cities are developed around river mouths and are vulnerable to combinations of river and groundwater flooding, exacerbated by high storm tides; Christchurch has experienced several such events recently. The increasing frequency of multiple hazard effects may prove problematic before the impacts of individual coastal hazards, such as coastal storm inundation, are noticed.

Methods have been developed overseas to assess vulnerability to multiple hazards. For example, Torresan et al (2012) and Rosendahl Appelquist and Halsnæs (2015) present regional vulnerability assessment methods, based on ranking (eg, 1–5) the vulnerability of bio-geophysical and socio-economic vulnerability indicators (such as coastal topography, geomorphology, vegetation, location of artificial protection). These indicators are a measure of the potential harm from a range of climate-related impacts (such as SLR, coastal storm inundation and coastal erosion).

A risk-based approach to managing coastal hazards (Policy 24 of NZCPS 2010) requires determination of the different likelihoods of different magnitude events and their consequences, which is complex for multiple hazards. There are few New Zealand examples of studies that have accounted for multiple hazards or their joint probability. Joint probability analyses have been conducted in New Zealand for offshore hazard sources from storm tides and waves (eg, Stephens et al, 2013; Allis et al, 2015; Stephens et al, 2015a). Joint probability analyses of storm tides and river flows were undertaken as part of flood modelling for the Buller River (Pearson, 2004; Wild et al, 2004). Joint probability methods are still being developed and are improving over time (eg, Wyncoll and Gouldby, 2015).

6.5 A guide to coastal hazard assessment

The purpose of a coastal hazard assessment is to identify the spatial extent and magnitude of hazards and to quantify the likelihood of hazards occurring, ideally in probabilistic terms or by way of scenarios supported by expert elicitation. This information is required by planners, asset managers and decision-makers. It is needed for input to the engagement process with

potentially affected communities (property owners and residents), iwi/hapū and stakeholders (see chapter 3 and chapter 8 onwards).

Guiding principles for hazard assessments

There is no single way to approach a coastal hazard assessment. Various combinations of data analysis, modelling and mapping techniques can be used, depending on factors such as the locality, data availability, cost and assets at risk.

What is important is to undertake the hazard assessments for a range of hazard magnitudes and likelihoods, SLR scenarios and sensitivities to climate change effects on waves and storm surges, rather than predetermining a particular SLR scenario.

Uncertainties and assumptions need to be transparent and documented.

Before any detailed coastal hazard assessment of any scale is undertaken, a region-wide hazard-exposure screening should guide priorities and subsequent more detailed assessments. A region-wide hazard assessment is useful in its own right to support land-use planning and adaptation planning processes for managing hazard risk across a region or district (chapters 9 and 10).

Generally, more detailed coastal hazard assessments, using multiple SLR scenarios (section 5.7) and sensitivity to changes in waves and storm surges (section 5.9) will be needed as input to:

- community engagement processes (chapters 3 and 7), to provide background information for communities, iwi/hapū and stakeholders about the increasing hazard exposure at local levels
- risk and vulnerability assessments (step 4, discussed in chapter 8)
- detailed land-use planning and adaptation planning processes (steps 5–8, discussed in chapters 8–10).

Hazard assessments are required at step 2 of the decision cycle (figure 29), to inform both council staff and affected communities, iwi/hapū and stakeholders; they provide the necessary information for making decisions during steps 3–10 of the decision cycle (see chapter 7 onward).

Ramsay et al (2012) describe methods and models that can be used to undertake coastal hazard assessments.

6.5.1 Checklist for coastal hazard assessments

The following provides a checklist of good practice for coastal hazard assessments, adapted from Ramsay et al (2012).

- Key technical, planning, infrastructure, civil defence and emergency management and parks and reserves sections of council have been involved in scoping the aims, objectives and intended outputs of the coastal hazard assessment, and at relevant times during the process of identifying coastal hazard areas. Engagement with relevant stakeholders, iwi/hapū and representatives of affected coastal communities may provide input and local knowledge to the hazard assessment.
- Available data for use in the assessment is identified at scoping stage, is adequate and appropriate for the intended application of the coastal hazard assessment, and any limitations are identified.
- A conceptual model of the sources (section 6.2) and impacts of coastal hazard and shoreline change processes (section 6.4) is developed and used to help scoping, facilitating

communication and identifying knowledge gaps and uncertainties. At the conceptual stage, it is useful to decide what levels of uncertainty are likely to be present in the hazard assessment and how those uncertainties might be addressed and presented (section 6.5.4 – uncertainty). For example, what is known, the known unknowns and the unknown unknowns (deep uncertainty).

- Where numerical or statistical modelling approaches are to be used, their use within the context of the conceptual model is clearly defined; any limitations, range of validity, uncertainties and assumptions are specified; the level and/or type of uncertainty is specified (section 6.5.4 – uncertainty); and as far as is possible the models are calibrated and verified.
- Uncertainty within each parameter or variable (where it exists) is captured, along with assumptions, and communicated. The impact on the final coastal change and/or inundation result is clearly conveyed (chapters 8 and 9).
- Where likelihoods cannot be assigned because of deep uncertainty around rates and magnitude of SLR, a risk-based approach means scenarios and expert elicitation will be required to assess the range of futures that could eventuate and their consequences (section 6.5.4 – scenarios).
- A range of SLR scenarios and sensitivity ranges for waves and storm surge are assessed for at least 100 years, and the sensitivity of the resulting coastal change and/or inundation is ascertained (section 6.5.4 – scenarios).
- Estimates and projections of coastal hazards are referenced to a clearly defined vertical or other baseline datum (eg, vertical datum for water levels and topography and a horizontal baseline for erosion).

Mapping and presentation of results is produced at a scale appropriate for the approach adopted, the underpinning data and tools used and the intended application of the coastal hazard information (section 6.6 – inundation mapping case study).

6.5.2 What scale of coastal hazard assessment is required, and where should we focus our effort?

Regional and local councils should coordinate hazard assessments with other councils in the region facing common threats from coastal hazards and SLR. A regional hazard assessment provides an opportunity to evaluate impacts that span multiple jurisdictions, assess and implement regional strategies, coordinate responses and leverage research and planning funds.

As a starting point, and before any detailed coastal hazard assessment at any scale, a region-wide hazard-exposure screening will guide priorities and subsequent more detailed assessments. In the absence of detailed site-specific hazard assessments, a region-wide hazard assessment is useful in its own right to support land-use planning and adaptation planning processes for managing hazard risk across a region or district (chapters 9 and 10).

Generally, more detailed coastal hazard assessments, using multiple SLR scenarios (section 5.7) and sensitivity to changes in waves and storm surges (section 5.9), will be needed as input to:

a. community engagement processes (chapters 3 and 7) to provide background information for communities, iwi/hapū and stakeholders about the increasing hazard exposure at local levels

b. risk and vulnerability assessments (step 4, covered in chapter 8)

c. detailed land-use planning and adaptation planning processes (steps 5–8, covered in chapters 8–10).

6.5.3 Regional hazard screening

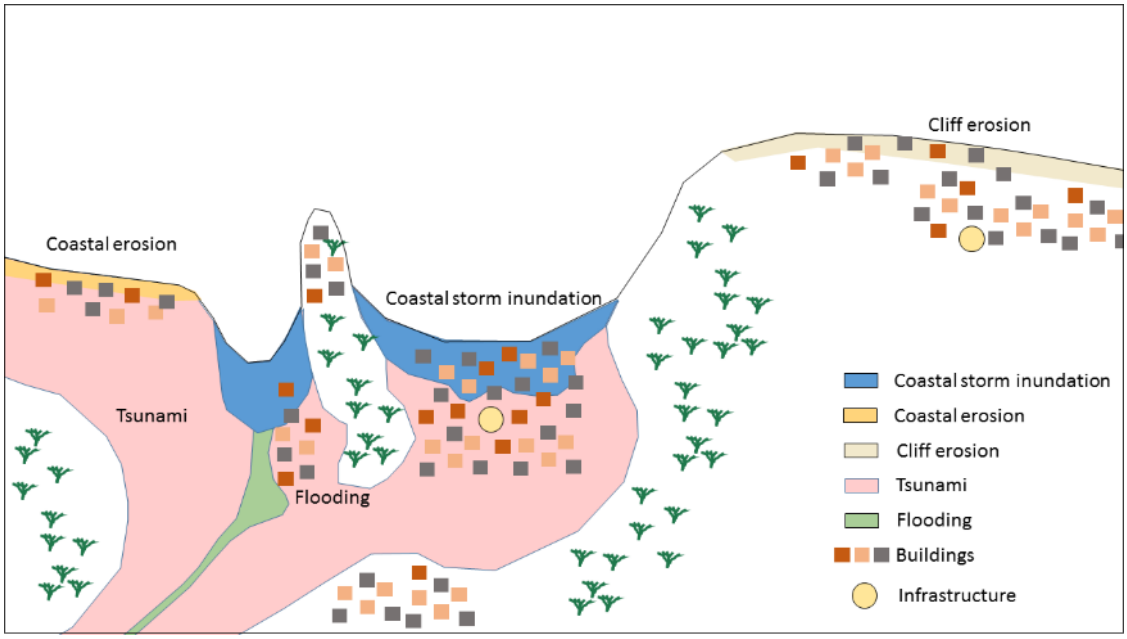
A regional hazard screening should identify areas that require more detailed assessments of coastal hazard exposure, for single or multiple hazards (eg, figure 43). Examples might be dense populations or high-value assets in low-lying areas, close to an eroding coastline or surrounding a lowland river or watercourse.

This screening analysis should start with a high SLR scenario (eg, H^+ scenario in section 5.7) to broadly identify areas potentially exposed to coastal hazards and to show where more detailed hazard (and ultimately risk and vulnerability) assessments should be focused. This initial hazard screening should highlight areas with the greatest exposure to coastal inundation and groundwater, for further investigation. The extent of coastal erosion is much more localised so requires a more nuanced approach around present erosion issues and determining the susceptibility to increased erosion due to climate change.

Hazard screening can be achieved in several ways:

- existing problems – council staff may be aware that some locations are already experiencing coastal hazard impacts, such as coastal storm inundation on Auckland's Tamaki Drive and coastal erosion on the North Taranaki coast. Wellington's south coast is experiencing increasing impacts on coastal infrastructure from storm tides and large wave events. These locations are obvious priorities for detailed assessment
- conversations with coastal communities, including property owners and residents, on local knowledge of events or changes
- expert elicitation – vulnerable areas can be identified by experienced staff with knowledge of the coastline, land elevation, its hazard sources, population density and existing asset value
- existing information, such as previous reports (eg, Parliamentary Commissioner for the Environment, 2015; Bell et al, 2015; or local or regional reports), or existing tools such as the coastal sensitivity index (Goodhue et al, 2012)
- geographic information systems analysis to identify low-elevation coastal land, such as Waikato Regional Council's coastal inundation tool (Waikato Regional Council, n.d) (section 6.6 – Case Study A)
- broad-scale hazard assessments using simple techniques and available data (see section 6.6 – Case Study E on areas susceptible to coastal erosion in Gisborne District)
- evaluating the impact of broad-scale hazard scenarios using available risk analysis software, such as RiskScape (NIWA and GNS Science (n.d)), which can be applied with relatively low effort and cost (see chapter 8 for risk and vulnerability assessments).

Figure 43: Regional hazard screening example



6.5.4 Coastal hazard assessment

Detailed coastal hazard assessments are required to map coastal hazard areas for specific hazards. The assessments are used as input for community, iwi/hapū and stakeholder engagement, and subsequent steps in the decision cycle (figure 29).

Figure 44 provides a framework to guide the approach to coastal hazard assessment (Stephens et al, 2017). The chart shows relationships between the existing situation, the appropriate level of uncertainty that could be considered based on that situation, the coastal hazard assessment scenarios to match that level of uncertainty, and the associated hazard assessment modelling complexity. The framework attempts to provide logical flow paths from left to right, depicted by the arrows that could guide the choice of hazard assessment scenarios, being cognizant of all stages within the hazard assessment; the land-use situation, hazard modelling, and the decision-making process. The decision being made and the type of uncertainty that needs addressing (see chapter 4) will guide the choice of hazard assessment (eg, modelling scenarios and the resulting complexity and cost).

The type of decision being made is grouped into three categories.

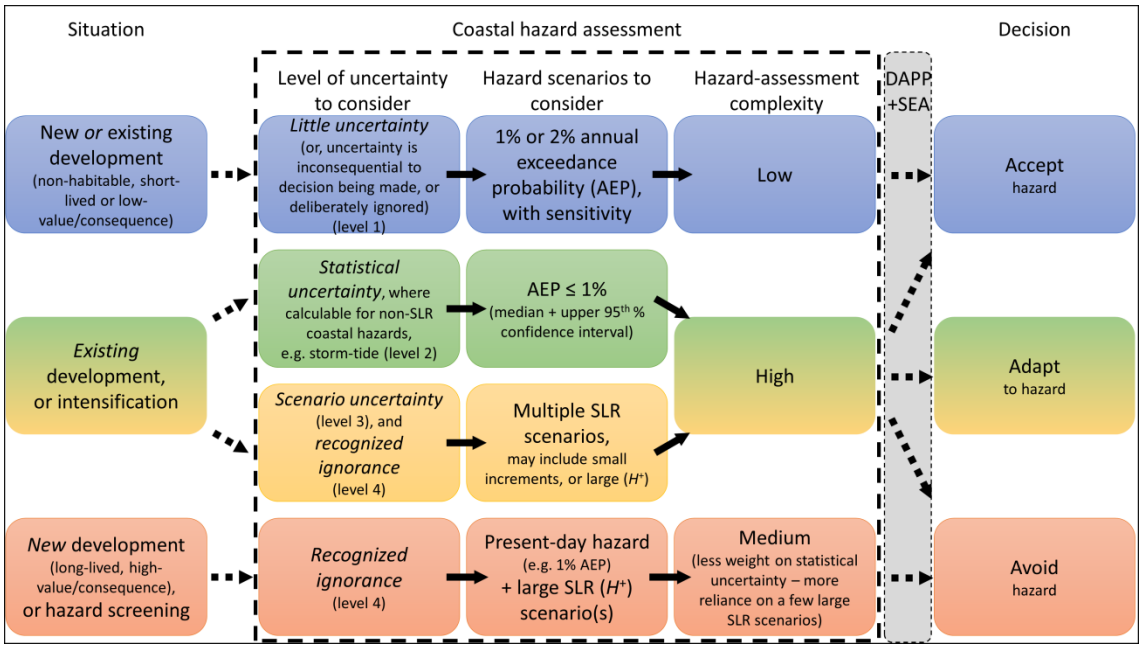
1 **Accept hazard** – where the risk of damage from coastal hazards and SLR is low or the asset can be easily adapted to cope with future SLR. Examples might be a toilet block, a surf-lifesaving hut or a culvert supporting a minor access way. The future for such assets is reasonably clear; that is, they are relatively easily replaced or relocated, so modelling effort can be kept simple and low cost, perhaps employing a simple 'building block' model to allow for various coastal hazard sources, or relying on expert judgement to decide on an appropriate floor or culvert elevation or setback distance.

2 **Adapt to hazard** – such as for existing areas of higher value development, the hazard assessment must provide sufficient information to inform the decision(s) to be made, often involving both present-day statistical uncertainty (where calculable for non-SLR coastal hazards such as storm tide), plus several SLR scenarios – thus, it is likely to be more complex and costly.

3 **Avoid hazard** – modelling effort can be kept relatively straightforward and low cost, focusing on an upper-range hazard scenario of at least the 1 per cent annual exceedance

probability (AEP),[79] hazard plus the H^+ SLR scenario (from chapter 5); the H^+ SLR scenario and coastal erosion has a longer timeframe beyond 2120 associated with it (section 5.7). The effects of this higher SLR are generally considerably larger than the uncertainty in the derivation of the 1 per cent AEP hazard. Such assessments also need to consider tsunami hazard exposure from any regional study undertaken primarily for civil defence emergency management purposes.

Figure 44: Uncertainty framework for coastal hazard assessments to support the dynamic adaptive planning pathways (DAPP) process, showing a logical flow from the situation, to the related level of uncertainty as determined by the situation, the hazard scenarios to model, the likely hazard modelling complexity, and the possible decision type



A distinction is drawn (represented by the dashed arrows and dashed box) between the situation, the coastal hazard assessment process, the DAPP process and socio-economic assessment (SEA), and the decision type. Hazard exposure screening (figure 45) can indicate the type of situation and level of uncertainty to address, which will guide the model scenario choices and required modelling complexity. Note: AEP = annual exceedance probability; SLR = sea-level rise. See section 5.7 and table 12 for SLR guidance. Adapted from: Stephens et al. (2017)

How sure are we? Uncertainty is important

When undertaking coastal hazard assessment, four types of uncertainty lead to different types of decisions and policies (eg, Walker et al, 2003, 2013). Assume that future coastal hazards:

1 are knowable or known (*little uncertainty*) (Level 1)

2 will behave probabilistically or stochastically in much the same way as the past (*statistical uncertainty*) (Level 2)

3 are well described by a few simple overarching scenarios (*scenario uncertainty*) (Level 3)

4 are unknown or disagreed upon by experts and/or stakeholders with no consensus of what the future might bring (*deep uncertainty*) (Level 4).

Some or all of these levels of uncertainty will typically be involved when making decisions. *Deep uncertainty* or *recognised ignorance* is defined as the situation where analysts *do not know*, or the parties to a decision *cannot agree on*, the appropriate conceptual models, the probability distributions used to represent uncertainty, and/or how to value the desirability of alternative outcomes (Lempert et al, 2003).

[79] See appendix F: Hazard occurrence probabilities and timeframes.

In a risk-based context, determining coastal hazard likelihood can be difficult, because it can involve any of the levels of uncertainty above.

The level of uncertainty present is related to the situation or type of decision being made (figure 44), although the decision will also depend on the outcome of dynamic adaptive pathways planning and socio-economic analyses. For low-risk, short-life assets, we can largely put aside uncertainty and make decisions using a reasonable 'best estimate' of coastal hazard likelihood at present-day MSL with a modest SLR (*little uncertainty*, Level 1).

Coastal hazards can be avoided (over at least the next 100 years) by adding an H^+ SLR scenario to a 'best estimate' of coastal hazard likelihood, such as 1 per cent AEP hazard event (*deep uncertainty*, Level 4). Coastal hazard assessment can be relatively simple in these cases. An H^+ scenario is advised for new areas of development (greenfields), or consideration of areas where urban intensification is proposed.

The greatest resource demands on coastal hazard assessments is for existing, exposed developments, where ongoing adaptation will be required to cope with rising sea level. Le Cozannet et al (2015) showed how the relative importance of the sources of uncertainties changes over the time: local coastal processes are the most important during the first part of this century, whereas uncertainties of future SLR scenarios largely dominate beyond 2080. *Statistical uncertainty* (Level 2) is relevant over short-term planning timeframes (up to 2050), but *scenario* and *deep uncertainties* (Levels 3 and 4) become dominant over longer planning timeframes, driven mainly by the unknown rates of SLR (Le Cozannet et al, 2015); all levels of uncertainty should be addressed (figure 44).

In her 2015 report, the Parliamentary Commissioner for the Environment recommended that:

> …in revising central government direction and guidance on sea level rise, specify that 'best estimates' with uncertainty ranges for all parameters be used in technical assessments of coastal hazards (Parliamentary Commissioner for the Environment, 2015, section 8.5).

While it is desirable to specify *statistical uncertainty* ranges for some parameters, this may not always be possible. The longer the timeframe, the increasing dominance of SLR on the outcome (where a 'best estimate' SLR is not possible). It is presently not possible to specify *statistical uncertainty* for the choice of representative concentration pathway (RCP) and SLR scenario (Buchanan et al, 2016).

Where likelihoods cannot be assigned because of uncertainty around rates and magnitude of SLR, a risk-based approach means the consequences of various scenarios need to be considered and their unknown likelihood managed (chapter 5).

Table 14 gives an example of how various components of a coastal hazard assessment might be characterised as to their level of uncertainty. Note that different levels of uncertainty may apply to the same component for different parts of the hazard assessment. For example, an assessment of future coastal storm inundation may contain statistical uncertainty based on present-day estimates of climate variability, plus scenario-based adjustments for future storm surge, plus both scenario-based and unknown uncertainty for SLR. Table 14 gives examples of the location and type of uncertainty for the calculation and mapping of coastal storm inundation hazard. Coastal hazard assessments should clearly show the location, level and nature of uncertainty in the calculation of the magnitude and likelihood of the hazards.

Table 14: Examples of location and level of uncertainty applied to components of a coastal hazard assessment

Location of uncertainty	Level of uncertainty			
	1: Little uncertainty	2: Statistical	3: Scenario	4: Unknown future
Conceptual model of hazard	• Present-day coastal hazards low-value short-lived asset	• Present-day coastal hazards high-value long-lived asset	• Future coastal hazards after a period of sea-level rise (SLR)	• Future coastal hazards after a period of SLR
Coastal hazard sources	• Storm tide	• Storm tide	• Storm tide climate change adjustment scenarios • SLR	• SLR
Model of hazard impacts	• Deterministic storm tide elevation using 'building block'	• Probabilistic storm tide elevation using 'extreme value' model	• SLR allowances	• H^+ SLR allowance
Coastal hazard assessment outcomes	• Mapped coastal hazard level and/or area for a single SLR scenario	• Present-day coastal storm inundation and coastal erosion mapped for a range of probabilities	• Maps of future coastal storm inundation and coastal erosion dominated by SLR	• Future coastal erosion (eg, spits and tidal entrances) • Very high SLR scenario

Red text indicates a climate change scenario. This table provides a few examples only and is not a comprehensive list. (Adapted from Walker et al, 2003.)

Use the 1 per cent annual exceedance probability and upper 95th percentile confidence interval for hazards

It is often possible to calculate the present day *statistical uncertainty* (Level 2) based on historical observations of the frequency and magnitude of coastal hazards. Experts can usually calculate with reasonable accuracy the likelihood and magnitude of a 1 per cent AEP (0.01 annual exceedance probability) event, and the statistical uncertainty in the 1 per cent AEP event magnitude. Often, because of limited data (eg, the lack of a long time series), it is difficult to accurately calculate the frequency and magnitude of events rarer than 1 per cent AEP, and 1 per cent AEP has been adopted as a suitable planning likelihood in many coastal hazard assessments for coastal inundation and erosion. Note that potentially catastrophic tsunami hazards are often assessed at larger and rarer 0.2 per cent AEP or less (eg, Power, 2013).

One per cent AEP refers to a 1 per cent chance of an event occurring or being exceeded in any year,[80] so it is a large and rare event (rare on an annual basis, but increasingly likely over longer timeframes. For example, such an event would have a 63 per cent chance of occurring at least once over a 100-year timeframe (appendix F), so it is 'about as likely as not' over 100 years). An AEP of 1 per cent is equivalent to a 100 year average recurrence interval (or 100 year return period). The 1 per cent AEP storm tide or coastal erosion event is a useful benchmark because it includes all sea-level processes and is rare on an annual basis but becomes more likely over a planning timeframe, and calculable, which makes it practical to assess.

[80] See appendix F: Hazard occurrence probabilities and timeframes.

Where the statistical uncertainty of the 1 per cent AEP event magnitude is large, the use of only the 'best estimate' of the extreme magnitude could over- or under-estimate the hazard at the 1 per cent AEP. It is recommend that coastal hazards be assessed at both the 'best estimate' of the 1 per cent AEP and the upper limit of its 95 per cent confidence interval (figure 44). The use of this estimate, and its upper 95 per cent confidence limit, enables the 'best estimate' to be contrasted with a conservatively large value, which the 1 per cent AEP will 'very likely' lie below and which meets the NZCPS 2010 (Policy 24) requirement to "identify areas in the coastal environment that are **potentially** affected by coastal hazards" (emphasis added).

If it is not possible to accurately calculate statistical uncertainty (insufficient data, or known unquantifiable physical process), then the 'best estimate' should be used. This could be supported with alternative scenarios to establish the sensitivity to the decision required, provided the assumptions and sources of uncertainty in those scenarios are made clear.

Sensitivity of storm tide and waves to climate change

It is possible to calculate the statistical likelihood (frequency and magnitude) of large storm tides and waves for present-day conditions, using available measurements and hindcast models. Future projections of changing storm conditions rely on global climate models, such as the Wave and Storm-Surge Projections (WASP) project discussed in section 5.8. The WASP results suggested possible future increases in storm surges of up to 10 per cent for large (99th percentile) surges and similar for wave heights. It is therefore recommended that sensitivity to climate change could be assessed by modelling 10 per cent increases in extreme (less than or equal to 1 per cent AEP) storm surges and wave heights. In most instances, however, increases of 10 per cent are unlikely to cause large changes in modelled inundation or erosion relative to other uncertainties, such as the upper limit of the 1 per cent AEP 95 per cent confidence interval for the relevant hazard or SLR. The sensitivity of storm tide and waves to climate change could be included where particularly high-detail, tight-risk tolerances or a more comprehensive range of possible futures are required to support decision-making for situations with high sensitivity to climate change.

What sea-level rise scenarios should be used for hazard modelling?

As a minimum, a coastal hazard screening assessment should assess the impact of at least 1 per cent AEP hazard, plus the H^+ SLR scenario (section 5.7). This should be used for prioritising those areas potentially exposed and assessing areas for any proposed greenfield development at the regional scale.

For detailed coastal hazard assessments at the district and local level, however, it is advised SLR scenarios are used (section 5.7) or increments of SLR to fully analyse and quantify the emergence of considerable hazard exposure and potential impacts from SLR to coastal resources, human health and safety. A coastal hazard assessment should address the relevance of the following questions during the assessment scoping phase (California Coastal Commission, 2015).

- What are the potential impacts from the highest possible SLR scenario plus elevated water levels from maximum expected storm tide, or from extreme coastal erosion?
- What is the minimum amount of SLR that causes inundation, erosion or saltwater intrusion concerns?
- How do inundation, erosion or saltwater intrusion concerns and extents change with different amounts of SLR?

- Are there any adaptation thresholds and associated triggers (allowing for implementation lead time) where SLR impacts become more severe?

Two approaches are used for selecting SLR scenarios:

1 identify increments of SLR heights (eg, 0.1 or 0.2 metre increments), then relate to likely bracketed time period(s) of occurrence across the range of scenarios or RCPs (section 5.7)

2 choose applicable years or timeframes, then apply the four SLR scenarios in section 5.7 (figure 27).

Table 11 links the two, providing guidance on the potential brackets on timing of various SLR heights.

The choice of SLR and AEP scenarios is shown in figure 45.

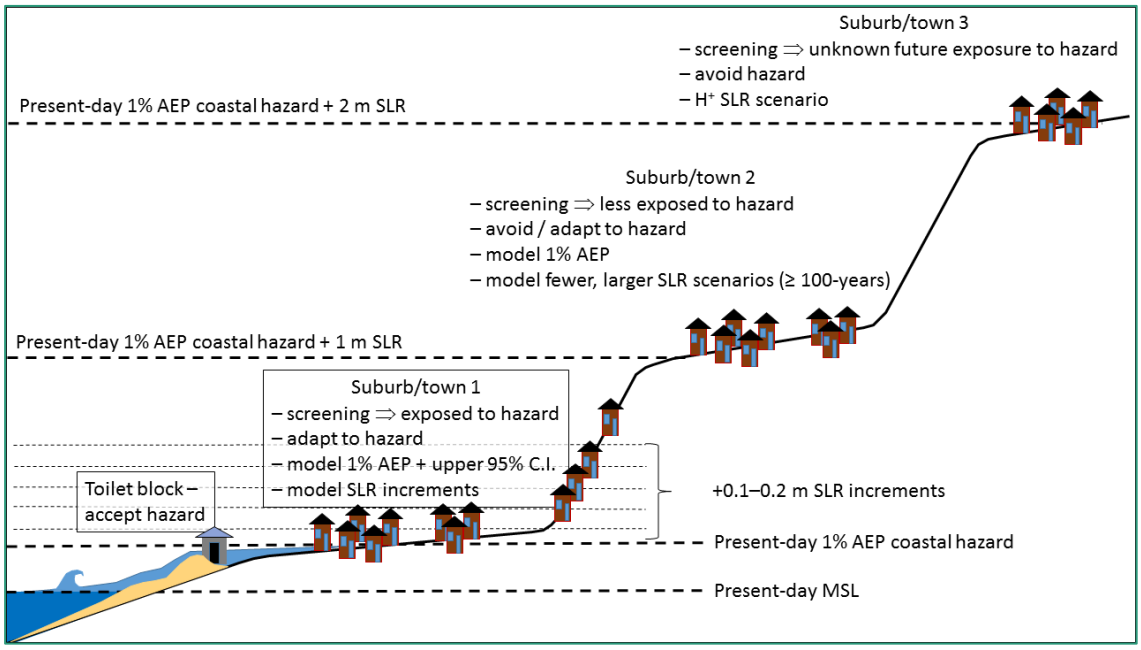
- For communities that are already vulnerable to coastal hazards, it is likely that critical adaptation thresholds and trigger points (decision points) could be reached at relatively low SLR thresholds (section 6.4.1), such as for Suburb 1 shown in figure 45. Suburb 1 is built on low-elevation land, close to the coast, and the hazard screening has identified that parts of the town are already exposed to 1 per cent AEP coastal storm inundation and coastal erosion.

  Two types of uncertainty need to be addressed: uncertainty in the evaluation of the 1 per cent AEP storm tide and coastal erosion at present-day MSL, and uncertainty in the future SLR. In this case, the hazard should be assessed for both the 'best estimate' of the 1 per cent AEP, and the upper limit of its 95 per cent confidence interval for the 1 per cent AEP storm tide and coastal erosion. The sensitivity to an up to 10 per cent increase in waves and storm surge due to climate change could also be demonstrated, if warranted to support decision-making. The depth, extent and frequency of the inundation and erosion hazards will grow incrementally with SLR (eg, figure 46), and trigger points (eg, frequency of nuisance or damaging inundation, or severe erosion events) may be reached well before 1 metre of SLR occurs. Areas on the hill slope will become progressively more exposed as sea level rises incrementally. In this case, the impacts of a few regular small (eg, 0.1–0.2 metre) SLR height increments should be assessed (on top of both the median and upper 95 per cent of the 1 per cent AEP hazard) to identify potential trigger points (for input to the dynamic adaptive pathways planning process and community engagement in steps 3–5 of the decision cycle).

- Suburb 2 is built on a raised coastal platform (figure 45), approximately 1.0 metre above present-day 1 per cent AEP sea level. Hazard screening shows no exposure to 1 per cent AEP coastal inundation or erosion at present-day MSL, but only after about 0.5 metres or more of SLR. There is little need to model the effects of small SLR increments. Coastal hazard assessment could instead focus on fewer SLR scenarios, accounting for at least 100-year timeframes, such as 0.5, 1.0, 1.5 metre SLR. Greenfield developments in this suburb will require careful scrutiny in these subsequent steps, to avoid increasing risk.

- Suburb 3 is built on a raised coastal platform, approximately 2.0 metres above present-day 1 per cent AEP sea level. Regional hazard screening shows no exposure to 1 per cent AEP coastal inundation or erosion at present-day MSL, and SLR is not expected to impact on this suburb for more than 100 years. A coastal hazard assessment could use a single median 1 per cent AEP hazard plus H^+ SLR scenario as input to any long-term adaptation planning (figure 45).

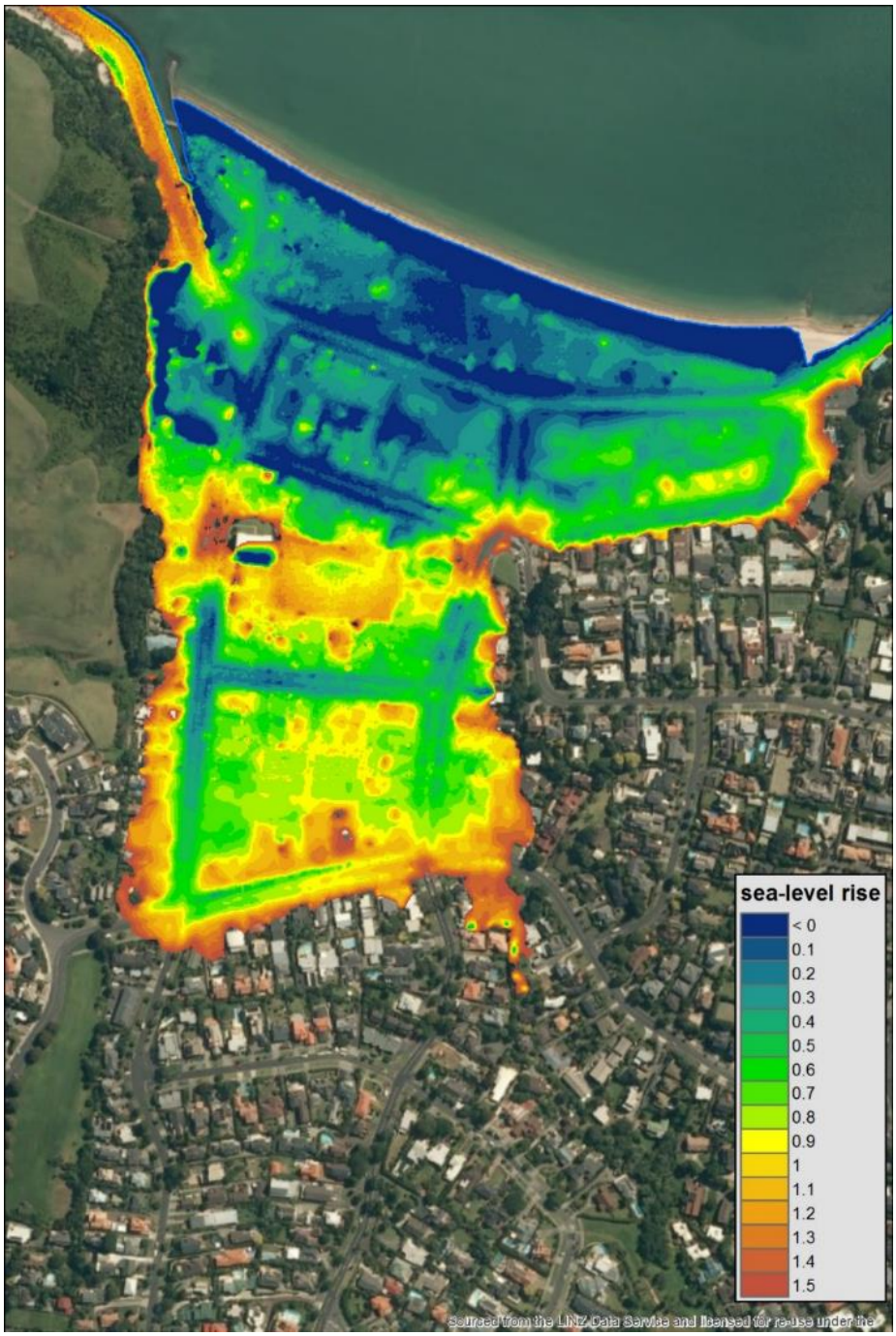
Figure 45: Choice of coastal hazard assessment model scenario based on hazard exposure



The degree of exposure indicates the level of uncertainty the coastal hazard assessment should address, the modelling scenarios required to help decision-making and the likely complexity of the hazard assessment (see figure 44). Note: AEP = annual exceedance probability; C.I. = confidence interval for the 1 per cent AEP hazard probability; m = metre; MSL = mean sea level; SLR = sea-level rise.

Figure 46 shows an example of a coastal hazard assessment that maps the exposure of Mission Bay, Auckland, to coastal storm inundation at various SLR increments. Mission Bay is similar to the Suburb 1 example shown above. The inundation mapping in figure 46 is relatively unsophisticated, using a static mapping technique to add SLR increments directly on top of the present-day median 1 per cent AEP storm tide elevation. Nevertheless, the map clearly indicates how inundation exposure might change incrementally with SLR, depending on location. Properties on low-elevation land close to the sea will face inundation at lower SLR, so will be affected sooner. Properties located further inland on higher elevation land are less exposed and will have longer to adapt to rising sea level.

Figure 46: Effect of 0.1 metre sea-level rise increments on coastal storm inundation exposure at Mission Bay, Auckland

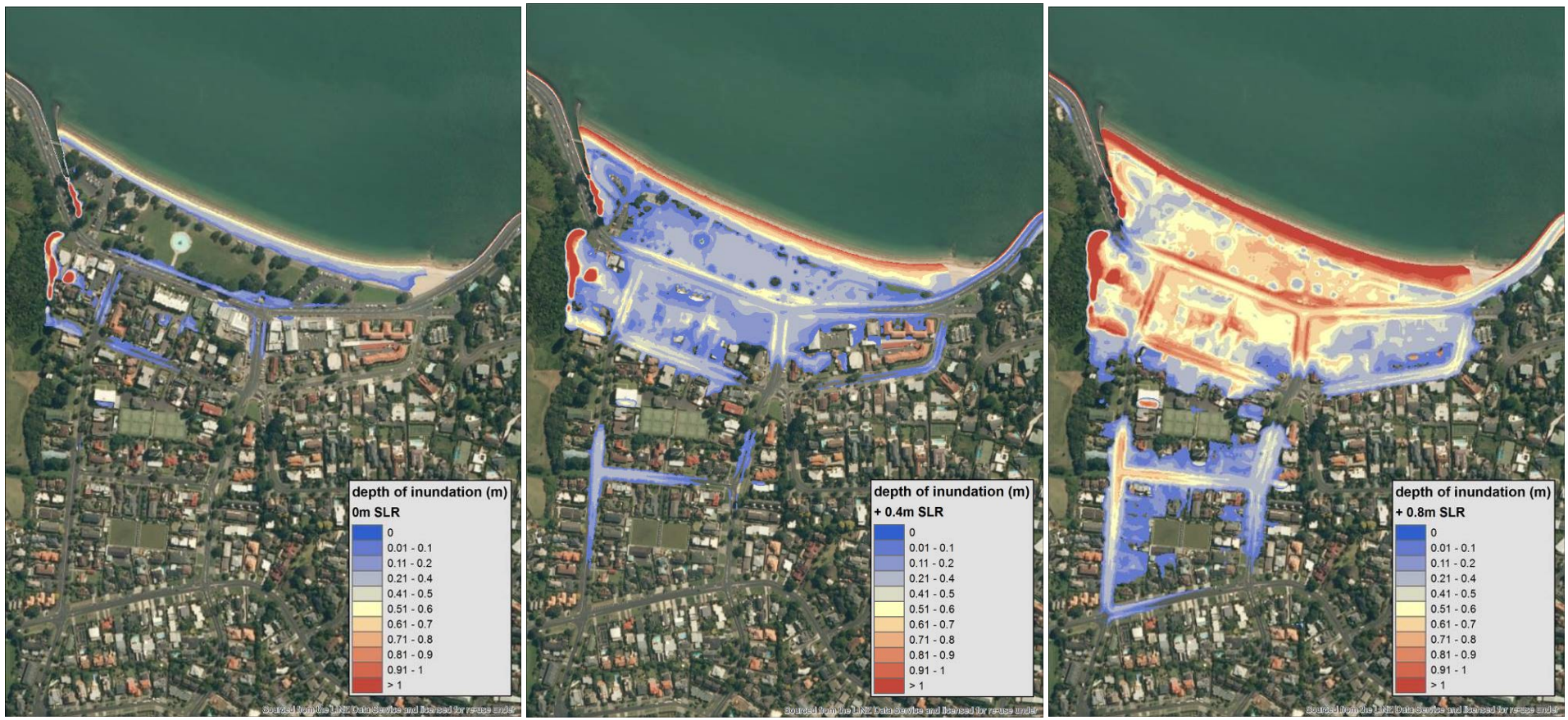


Sea-level rise increments have been added onto the 1 per cent annual exceedance probability storm tide elevation, which was calculated for the present-day mean sea level. Graphics: Sanjay Wadhwa, NIWA; based on Auckland Council Light Detection and Ranging (LiDAR) data. Source: Stephens et al. (2017)

BOX 14: CASE STUDY: MAPPING THE EFFECTS OF SEA-LEVEL RISE IN MORE DETAIL

- Mission Bay in Auckland has existing development on low-elevation land adjacent to the sea. The seaward part of Mission Bay is similar to Suburb 1 in figure 45.
- Figure 52 shows that developed low-lying areas like Mission Bay are likely to reach decision points before 1 metre of sea-level rise (SLR) (the modelled scenario) occurs, that is, Mission Bay could be likened to Suburb 1 in figure 45. In this way, the mapping has also acted as a hazard screening tool. For areas susceptible to present-day coastal storm inundation like Mission Bay, further modelling of additional SLR scenarios (small increments) and statistical uncertainties could be used to determine vulnerability and risk (chapter 8), and to support planning strategies and future adaptation decisions (chapters 9 and 10). For illustrative purposes, smaller SLR increments were mapped for this guidance, for Mission Bay only, and are shown in figure 46.
- In section 6.5.4 it is suggested that, for such locations, the impacts of regular, small (0.1–0.2 metre) SLR height increments should be assessed (on top of both the median and upper 95 per cent of the 1 per cent annual exceedance probability (AEP) hazard) to identify potential adaptation thresholds and trigger points (for input to the dynamic adaptive pathways planning process and community engagement).
- In this case study, two types of map show the potential effects of SLR increments on coastal storm inundation and could be included in a coastal hazard assessment.
- Figure 46 shows an example of a coastal hazard assessment that maps the area of exposure to coastal storm inundation at various SLR increments. The inundation mapping in figure 46 is relatively unsophisticated, using a static mapping technique to add SLR increments directly on top of the present-day median 1 per cent AEP storm tide elevation. Nevertheless, the map clearly indicates how inundation exposure might change incrementally with SLR, depending on location. Properties on low-elevation land close to the sea will face inundation at lower SLR, so will be affected sooner. Properties located further inland on higher elevation land are less exposed and it will take longer before inundation from SLR affects them.
- Figure 47 shows the depth (and area) of inundation for a 1 per cent AEP storm tide at present-day mean sea level (MSL), and two SLR scenarios, plus 0.4 metres and plus 0.8 metres. The maps show there is little exposure to coastal storm inundation at present, but this will increase as the sea rises. The maps also show the increasing depth (severity) of future inundation.
- Figure 48 shows the frequency (and area) of inundation for a 1 per cent AEP storm tide at present-day MSL, and two SLR scenarios, plus 0.4 metres and plus 0.8 metres. The maps show that coastal storm inundation is infrequent at present-day MSL but becomes increasingly likely with SLR. In combination with figure 47, the maps show both the expected depth and frequency of future inundation.
- The combination of these plots provides information that is more useful for decision-making than any of the plots in isolation. For example, a property located beside the first street back from the sea is safe right now, but after 0.8 metres of SLR can expect to be inundated about 10 times per year by about 0.5 metres or more of water.

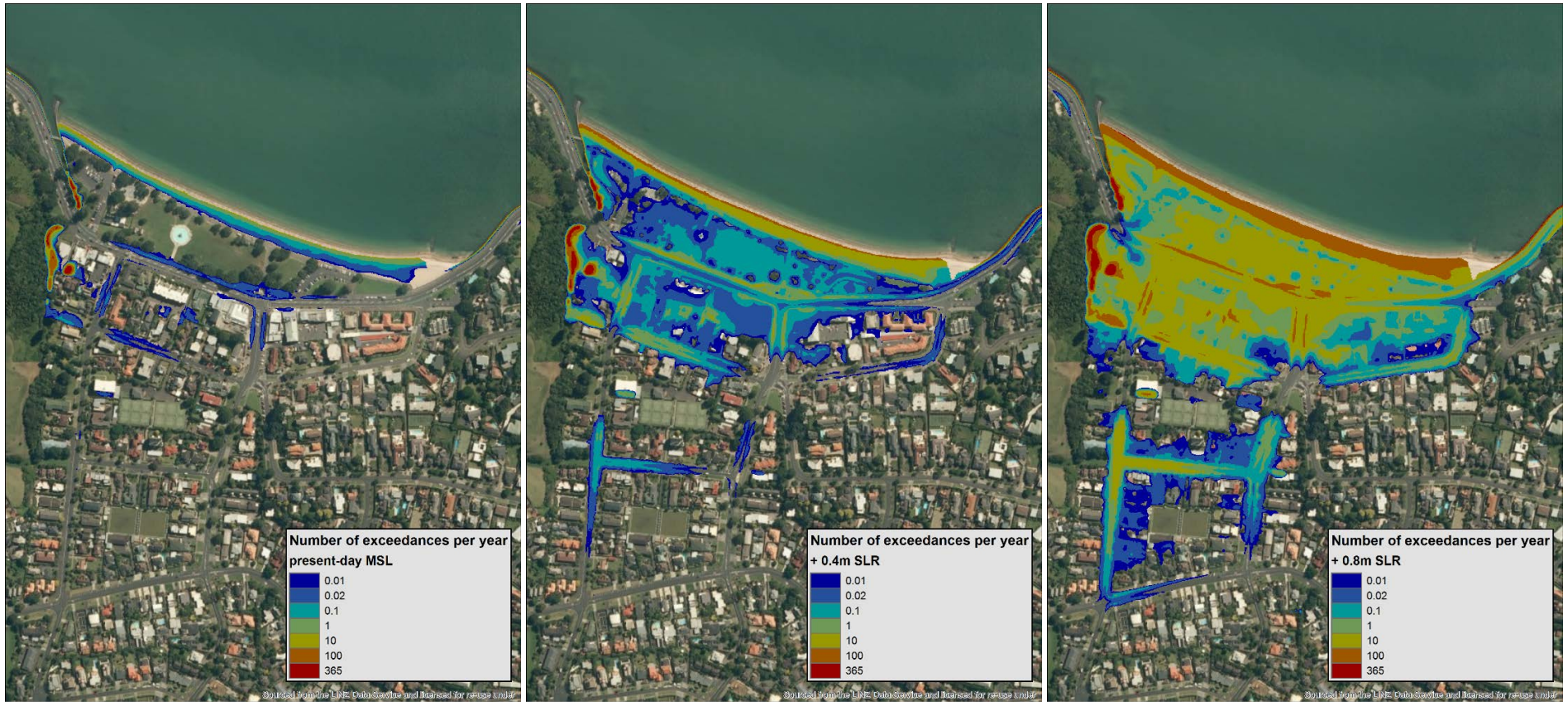
Figure 47: Depth of inundation at Mission Bay, Auckland, for a 1 per cent annual exceedance probability storm tide covering present-day mean sea level and two sea-level rise scenarios



Left: 1 per cent annual exceedance probability storm tide at present-day mean sea level. Middle: plus 0.4 metres sea-level rise (SLR). Right: plus 0.8 metres SLR.

Inundation was modelled using a static geographic information system technique. All areas below the modelled sea level are shown as inundated, regardless of connection to the sea – some inland areas may not become inundated as shown. Graphics: Sanjay Wadhwa, NIWA; base maps were developed from Auckland Council Light Detection and Ranging (LiDAR) data

Figure 48: Frequency of inundation (exceedances per year) at Mission Bay, Auckland, for a 1 per cent annual exceedance probability storm tide, covering present-day mean sea level and two sea-level rise scenarios



Left: 1 per cent annual exceedance probability storm tide at present-day mean sea level. Middle: plus 0.4 metres sea-level rise (SLR). Right: plus 0.8 metres SLR.

Inundation was modelled using a static geographic information system technique. All areas below the modelled sea level are shown as inundated, regardless of connection to the sea – some inland areas may not become inundated as shown. Graphics: Sanjay Wadhwa, NIWA; base maps were developed from Auckland Council Light Detection and Ranging (LiDAR) data

6.5.5 Data requirements for coastal hazard assessments

Environmental monitoring information is crucial to coastal hazard assessment and influences the level of detail and uncertainty. Environmental data can be used directly to inform coastal hazard assessment but is more commonly used as input to models that build on the monitoring data to extend it in time and space. Data provides boundary conditions to force models and is used to calibrate models and verify their output. For example, a field study to obtain multiple short data records (eg, one month) is often used to support detailed hydrodynamic modelling of a specific site or area. Environmental data is also required to monitor the future progression of climate change impacts on the coast and should form part of adaptation planning. Short-term monitoring data will not be useful for considering the effects of climate change on hazard risk.

Long (multi-decadal) data records are particularly useful in a changing climate with background climate variability and are required to determine extreme-value distributions, climate variability and climate change. One potential pitfall of monitoring over short timescales, especially for small regions, is that it is easy to mistake natural variability for a trend in SLR. For example, climate cycles such as ENSO, and the longer 20–30 year IPO, create long-period variability in MSL of up to plus or minus 0.2 metres (supplementary information sheet 8, in appendix J) and can mask the acceleration in SLR in recent decades (eg, Sweet et al, 2014; Wahl and Chambers, 2016; chapter 5).

It is also important to document the frequency of coastal storm inundation and erosion because the increasing frequency of these events will provide input to setting triggers and adaptation thresholds for the number of these nuisance or damaging events.

Table 15 shows types of environmental data and their potential use within coastal hazard assessments.

Table 15: Environmental data types and their potential use in coastal hazard assessment

Data	Derived information	Use
Sea-level record	Tidal elevations	Land–sea boundary definition
		Boundary conditions or calibration data for hydrodynamic models
		Component for building block or probabilistic extreme sea-level analysis
	Storm surge	Component for building block or probabilistic extreme sea-level analysis
	Mean sea-level anomaly (MSLA)	Component for building block or probabilistic extreme sea-level analysis
	Mean sea level (MSL)	Define baseline MSL for a specified period relative to local vertical datum (LVD), for tidal or extreme sea-level analysis
		Monitor SLR and climate variability
	Sea-level maxima	Extreme sea level frequency-magnitude distribution (at least 10-year-long records)
		Benchmark of historical maximum sea level
		Boundary conditions or calibration data for hydrodynamic models during extreme event scenarios
Wave record	Wave height, period and direction	Boundary conditions or calibration data for hydrodynamic wave models
		Extreme wave frequency-magnitude distribution (at least 10-year-long records)

Data	Derived information	Use
		Input to empirical wave setup and runup model
		Monitor climate variability and climate change effects on waves
Beach profile records	Beach slope, position and volume	Input to wave setup and runup models
		Input to beach-erosion models. Useful to survey post-storm erosion profiles
Historical storm tide elevation and wave runup data	Coastal hazard markers and elevations	Verification data for coastal storm inundation and beach erosion models. Ideally collected after large storm events
Satellite altimetry	Sea level and wave height	Mean sea level and MSLA, mean wave conditions
Aerial photography, satellite imagery	Maps	Shoreline change, vegetation and land-use change, overlay on hazard maps
Seabed shape	Model bathymetry	Seabed for hydrodynamic or empirical models
Topography (from topographic maps, point surveys, Light Detection and Ranging (LiDAR), photogrammetry)	Seabed shape	Geographic information systems-based static inundation mapping
		Topography for hydrodynamic inundation model
		Definition of coastal hazard areas
Meteorology	Wind velocity, air pressure, rainfall	Input to hydrodynamic or empirical storm surge and wave models
Sediment grain size	Sediment grain size	Beach erosion models
Piezometer	Groundwater level and chemistry	Groundwater level and salinity response to sea-level change

See also chapter 11 on monitoring and review.

6.5.6 Additional considerations when applying coastal hazard assessment

Freeboard

Coastal hazard assessments will be used to inform planning, asset and infrastructure design and decision-making (chapter 9). Option evaluation will be based on selected hazard scenarios involving modelling of a relatively extreme hazard event plus an appropriate SLR.

Freeboards[81] are applied to account for additional factors that may not be captured in the chosen hazard scenario. The New Zealand Standard for Land Development and Subdivision Infrastructure (NZS 4044:2010, referred to as 'the standard' in this chapter), defines freeboard as:

> …a provision for flood level design estimate imprecision, construction tolerances, and natural phenomena (such as waves, debris, aggradations, channel transition, and bend effects) not explicitly included in the calculations (p 25).

It can also cover vehicle wakes when streets or roads are flooded. Freeboard should definitely not be used to also cover for uncertainty in SLR and climate change effects, however.

[81] Freeboard is measured from the top water level to the building platform level or the underside of the floor joists or underside of the floor slab, whichever is applicable (NZS 4044:2010).

What is an appropriate freeboard to apply on top of the chosen hazard elevation?

Section 4.3.5.1 of the standard recommends that the "secondary stormwater system flood level shall be based on the climate change-adjusted 100-year return period storm" (ie, 1 per cent AEP). The focus of the standard is on flooding from the upstream catchment, rather than from the sea. Flooding from coastal storm inundation is different from catchment flooding in that an additional allowance for SLR is required on top of the climate change adjusted 100-year average recurrence interval storm tide that causes flooding.

Freeboard allowances for 'habitable' dwellings currently used by local government range from 0.3–0.5 metres. The freeboard to be applied from this range in the standard also relates to the level of confidence in the flood level predictions, as well as the other matters described in the standard.

Note that, for coastal storm inundation, the 'top water level' should include storm tide plus the wave setup. Wave runup should not be included in calculation of the top water level, but an additional wave runup allowance is provided for separately, as described below.

Wave *setup* or wave *runup*?

How should assessments of wave setup and runup be used when developing rules controlling resource and building consents?

Wave setup is an integral component of the total water level that potentially could cause direct or near-continuous inundation of 'green water' onto coastal land. The combined storm tide plus wave setup level is therefore important for direct and quick-response coastal inundation.

The combined storm tide plus wave runup level is relevant to beach erosion and wave impact on seawalls and sand dunes and can result in wave overtopping. Overtopping by wave runup involves 'wave splash', 'wind spray' and sporadic shallow overwash of flowing 'green water' (depending how high up the wave setup level is). Wave runup may not necessarily cause substantial flooding, compared with more direct inundation from wave setup, but this also depends on the capacity of the drainage system behind the overtopped barrier. Whereas wave runup is arguably the most relevant design criterion for properties and infrastructure within several tens of metres of the coastline. Flooding and erosion by wave runup and overtopping is often localised and site specific, and the overtopping discharge volume is unlikely to cause widespread inundation at locations 100 metres back from the coast (notwithstanding barrier collapse or landward down-sloping land). Wave overtopping caused coastal inundation on Tamaki Drive, Auckland, in April 2014 (figure 35).

To estimate the expected inland extent of wave runup, Stephens (2016) applied the formula of Cox and Machemehl (1986), including the modification to include a decreasing landward slope from FEMA (2005). The formula suggests that the **probable maximum runup excursion** is approximately **30 metres inland** from the dune crest, berm or seawall (using parameters that lead to relatively large runup excursion, such as a 2 metre overtopping elevation, 20-second wave period and 1:5 landward slope). Shand et al (2014) obtained an excursion distance of 10–15 metres during their coastal erosion hazard zone assessment for selected Northland sites.

As an **alternative** to a coastal hazard setback, an additional **0.5 metre wave runup allowance** could be applied to account for wave runup effects, over and above the land elevation. This wave runup allowance should be applied within 10–30 metres of the seaward dune or seawall crest. This is shown in figure 49. A wave runup allowance **larger than 0.5 metres** may be required **within 10 metres** of the seaward dune or seawall crest and may require a site-specific assessment by a suitably qualified person.

Within 30 metres of the seaward dune or seawall crest, apply the higher of either the:

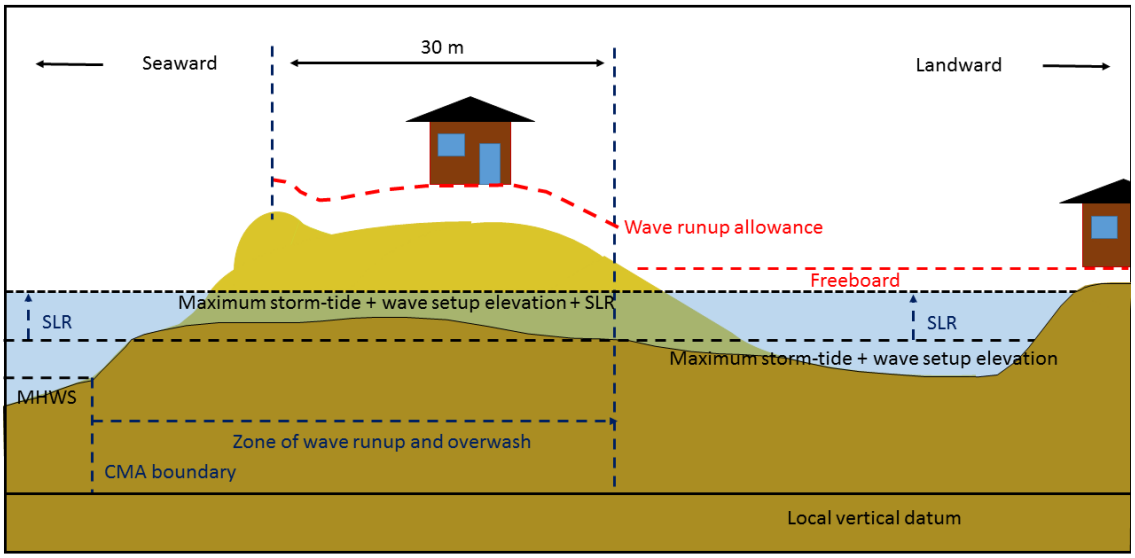
1 chosen coastal storm inundation elevation plus freeboard

2 land elevation plus 0.5 metres wave runup allowance.

Wave runup has a finite amplitude. The wave runup allowance should therefore apply only to land of elevation lower than the assessed 1 per cent AEP storm tide plus wave runup elevation.

Aside from the generic wave runup allowance suggested here, detailed wave overtopping assessments can be undertaken on a site-specific basis, such as that by Tonkin+Taylor (2016a).

Figure 49: Additional wave runup allowance relative to the land surface within 30 metres of the seaward dune or seawall crest



Note: CMA = coastal marine area; MHWS = mean high water spring tide; SLR = sea-level rise.
Source: Stephens (2016)

6.6 Coastal hazard assessment examples and case studies

This section provides examples and case studies of recent coastal hazard assessments or tools that have been developed. It is recommended that the uncertainty around the allowance for sea-level rise is more comprehensively addressed by adequately including sea-level rise scenarios, as recommended in chapter 5 and the approach outlined in section 6.5.4.

Case study A: Coastal inundation tool (Waikato Regional Council)

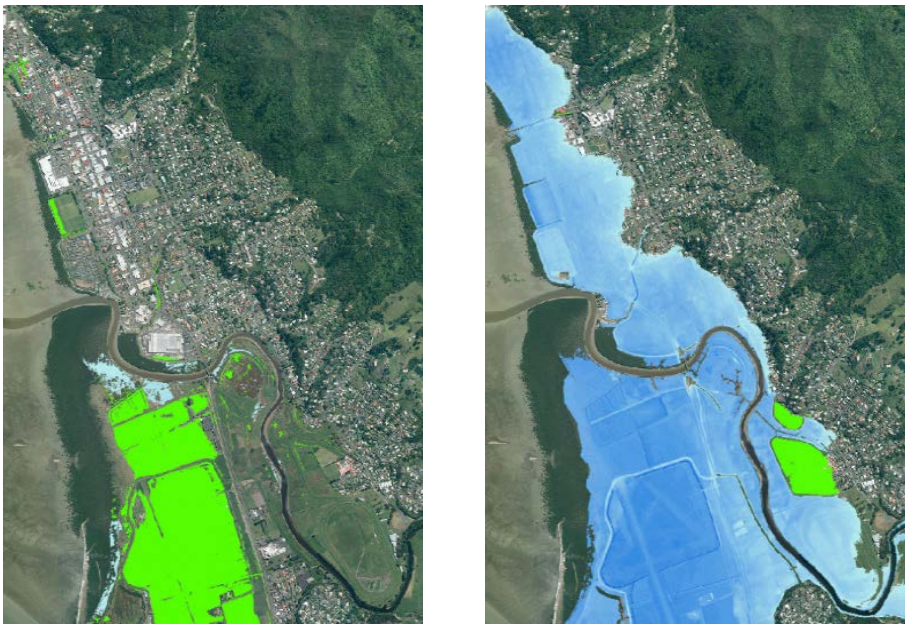
Waikato Regional Council has developed a coastal inundation tool (Waikato Regional Council, n.d) that is designed to raise awareness of the susceptibility of coastal areas to coastal inundation from tides, storms (no waves) and projected sea-level rise (SLR) at a regional scale. The tool is not designed to provide specific information that could be used to define actual coastal inundation hazards, or for defining minimum floor levels for specific properties. The tool is used for screening to identify areas where more detailed coastal hazard assessment might be required.

The coastal inundation tool used static geographic information system mapping to map potential coastal storm inundation, given user-selected sea-level scenarios. The tool includes guidance on a set of plausible sea levels, which are based on detailed analyses of sea-level records and a tidal model. Extreme sea levels (not including SLR) are included in the tool, calculated using a 'building block' extreme sea-level method. They have an unknown likelihood of occurrence. Thus the tool does not associate probabilities of occurrence to extreme sea levels but provides a plausible range of extreme sea levels, based on present-day conditions.

The tool allows for testing SLR scenarios relative to present-day mean sea level, by adding an SLR component to the present-day extreme sea level. Thus it is well suited for large-scale, long-term, scenario-based planning where the range of consequences are being assessed. This approach is well suited to use in pre-planning discussions and community engagement, as set out in chapters 3, 7 and 8 of this guidance.

Feedback from users has been positive and shows how the tool has raised the awareness of coastal inundation issues in the Waikato region. The Council believes the level of community feedback was improved by an extensive communications effort, especially between regional and local councils, before the tool was launched.

Figure 50: Coastal storm inundation at Thames for different scenarios using the Waikato Regional Council coastal inundation tool



Left: mean high water spring tide elevation at present-day mean sea level. Right: maximum storm tide elevation plus 1 metre sea-level rise.

Note: Blue shading = areas of predicted inundation; green-shading = areas lower than the sea level but not connected to the sea (and not inundated). Source: Waikato Regional Council (n.d)

Case study B: Coastal calculator (NIWA)

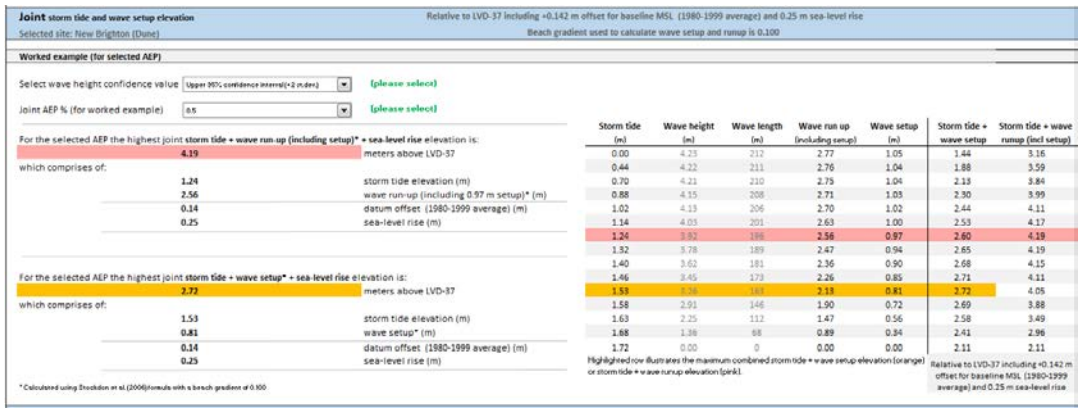
The coastal calculator (Allis et al, 2015) was developed to provide coastal hazard source elevations, along with their likelihood of occurrence, for coastal hazard risk assessment. The information in the calculator is suitable for either coastal storm inundation or coastal erosion assessments. The coastal calculator is a user-friendly way to present complex information, serving both as a database, a computer and an interactive presentation tool. Rather than presenting coastal hazard information in written form, such as tables, the calculator allows the user to explore the sensitivity of coastal hazards to location, sea-level rise (SLR) and beach state.

The coastal calculator includes extreme sea-level and wave analyses from monitoring data; storm tide and wave hindcast models verified against data; joint probability analyses of storm tides and waves, analysis of beach profiles, empirical wave setup and runup models verified against historical observations. The coastal calculator provides coastal hazard information in a way that meets the recommended requirements for risk-based coastal adaptation:

- output clearly related to local vertical datum
- high level of modelling detail undertaken in a probabilistic framework, including multi-year wave and storm tide hindcasts, statistically robust extreme-value modelling and joint probability modelling of both storm tides and waves; models are underpinned by monitoring data
- clear presentation of the expected frequency and magnitude of hazard sources and the statistical uncertainties of the frequency and magnitude
- reporting in several likelihood terms: annual exceedance probability, average recurrence interval and expected number of exceedances
- likelihood clearly related to (user-selected) planning timeframe
- flexible treatment of SLR, which can include a range of scenarios or increments of SLR (see chapter 5).

The coastal calculator has been built for the Bay of Plenty, Gisborne, Nelson, Tasman and Canterbury regions to provide information for coastal hazard assessment (Goodhue et al, 2015; Robinson et al, 2014; Robinson and Stephens, 2015; Stephens et al, 2014, 2015a).

Figure 51: Combined (joint probability) storm tide and wave setup and runup elevations



Joint storm tide and wave setup elevation

Selected site: New Brighton (Dune)

Relative to LVD-37 including +0.142 m offset for baseline MSL (1980-1999 average) and 0.25 m sea-level rise

Beach gradient used to calculate wave setup and runup is 0.100

Worked example (for selected AEP)

Select wave height confidence value: Upper 95% confidence interval(+2 m.dev) (please select)

Joint AEP % (for worked example): 0.5 (please select)

For the selected AEP the highest joint **storm tide + wave run-up (including setup)* + sea-level rise** elevation is:

4.19	meters above LVD-37

which comprises of:

1.24	storm tide elevation (m)
2.56	wave run-up (including 0.97 m setup)* (m)
0.14	datum offset (1980-1999 average) (m)
0.25	sea-level rise (m)

For the selected AEP the highest joint **storm tide + wave setup* + sea-level rise** elevation is:

2.72	meters above LVD-37

which comprises of:

1.53	storm tide elevation (m)
0.81	wave setup* (m)
0.14	datum offset (1980-1999 average) (m)
0.25	sea-level rise (m)

* Calculated using Stockdon et al.(2006)formula with a beach gradient of 0.100

Storm tide (m)	Wave height (m)	Wave length (m)	Wave run up (including setup)	Wave setup (m)	Storm tide + wave setup	Storm tide + wave runup (incl setup)
0.00	4.23	212	2.77	1.05	1.44	3.16
0.44	4.22	211	2.76	1.04	1.88	3.59
0.70	4.21	210	2.75	1.04	2.13	3.84
0.88	4.15	208	2.71	1.03	2.30	3.99
1.02	4.13	206	2.70	1.02	2.44	4.11
1.14	4.03	201	2.63	1.00	2.53	4.17
1.24	3.92	196	2.56	0.97	2.60	4.19
1.32	3.78	189	2.47	0.94	2.65	4.19
1.40	3.62	181	2.36	0.90	2.68	4.15
1.46	3.45	173	2.26	0.85	2.71	4.11
1.53	3.26	163	2.13	0.81	2.72	4.05
1.58	2.91	146	1.90	0.72	2.69	3.88
1.63	2.25	112	1.47	0.56	2.58	3.49
1.68	1.38	68	0.89	0.34	2.41	2.96
1.72	0.00	0	0.00	0.00	2.11	2.11

Highlighted row illustrates the maximum combined storm tide + wave setup elevation (orange) or storm tide + wave runup elevation (pink).

Relative to LVD-37 including +0.142 m offset for baseline MSL (1980-1999 average) and 0.25 m sea-level rise

A worked example for a single user-specified annual exceedance probability (10 per cent AEP used here), and maximum combined storm tide plus wave setup elevation for a range of annual exceedance probabilities.

Case study C: Coastal inundation by storm tides and waves in the Auckland region (Auckland Council)

Coastal storm inundation areas and depths were commissioned by Auckland Council for the entire Auckland region, to inform emergency management and natural hazard planning in the Auckland Unitary Plan (Stephens et al, 2016). Figure 52 shows an example of the coastal storm inundation mapping at Mission Bay, Auckland. Coastal storm inundation elevations from storm tides and waves were calculated using a probabilistic framework (at present-day mean sea level (MSL)). Sea-level rise (SLR) scenarios of plus 1 metre and plus 2 metres were added to the 1 per cent annual exceedance probability (AEP) coastal storm inundation elevations at present-day MSL, and inundation was mapped.

Figure 53 shows a synthesis of the relationships between the study requirements, type of uncertainty considered, scenarios modelled and modelling complexity. The mapping was not commissioned to explicitly consider all the scenarios recommended in this guidance, for example, short-lived versus major new infrastructure. Nevertheless, figure 53 shows how the studies could be framed in terms of the suggested framework in figure 44. Figure 53 shows that the study included both statistical and scenario uncertainty, plus an allowance for the deep uncertainty surrounding SLR – so the study has the ingredients required to facilitate decision-making by clearly separating the various uncertainty types.

The statistical probabilities (ie, AEP) of coastal storm inundation were modelled. The median AEP values only were used, but confidence intervals were not presented because the study considered relatively long timeframes (at least 100 years) with high (plus 1, plus 2 metre) SLR scenarios. The scenario uncertainty of SLR would dominate the statistical (AEP) uncertainty, therefore, meaning that the additional effort of mapping of confidence intervals would provide limited additional benefit for decision-making.

The supporting maps provide a useful tool for council to understand and communicate the potential hazard from coastal storm inundation and SLR through their online geographic information system viewer.[82] These hazards and their associated risks will need to be addressed in a community-wide planning sense in the decades to come. This was part of the information used by the Council to impose planning controls to ensure that coastal storm inundation is considered in planning today, to avoid increasing risk from climate change and SLR in future, and to help with building resilience (through design of habitable floor levels).

Figure 52 shows that developed low-lying areas like Mission Bay are likely to reach decision points before plus 1 metre of SLR (the modelled scenario) occurs, that is, Mission Bay could be likened to Suburb 1 in figure 45. In this way, the mapping has also acted as a hazard screening tool. For areas susceptible to present-day coastal storm inundation like Mission Bay, further modelling of additional SLR scenarios (small increments) and statistical uncertainties could be used to further determine vulnerability and risk (chapter 8) and to support planning strategies and future adaptation decisions (chapters 9 and 10).

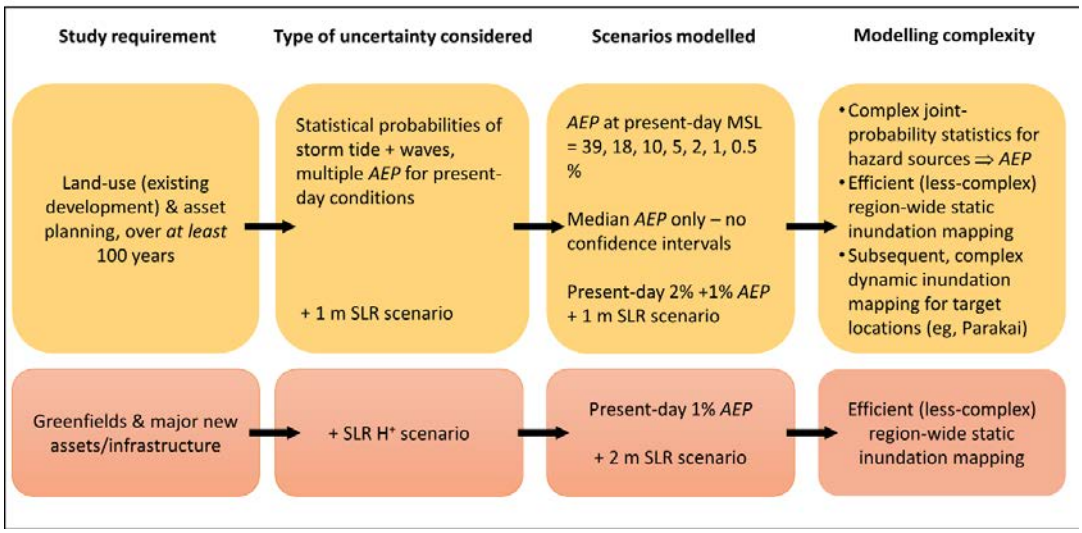
The maps (eg, figure 52) efficiently defined coastal storm inundation areas at a regional scale, as required for regional policy development, and identified areas where further work could improve the hazard assessment, such as more detailed assessment of the extreme sea levels or consideration of overland flow paths. The Parakai, West Auckland, area was identified as one such area, and the coastal storm inundation maps were revised using local water-level measurements and a dynamic inundation model (Stephens et al, 2016). The Parakai case study is described next, to contrast static and dynamic inundation modelling methods.

82 See http://maps.aucklandcouncil.govt.nz/aucklandcouncilviewer/.

Figure 52: Coastal storm inundation mapping example at Mission Bay, Auckland

Left: aerial photograph of Mission Bay. Right: with present-day 1 per cent annual exceedance probability storm tide, plus wave setup elevation superimposed (purple shading), plus 1 metre sea-level rise (SLR) (light shading) and plus 2 metre SLR (orange shading). Source: Auckland Council

Figure 53: Relationship between study requirement, type of uncertainty considered, scenarios modelled and modelling complexity, arising from the Auckland coastal inundation studies



Note: AEP = annual exceedance probability; MSL = mean sea level; SLR = sea-level rise.

Case study D: Static versus dynamic inundation mapping (Auckland Council)

This case study compares static and dynamic inundation mapping results over a wide floodplain at Parakai, West Auckland (Stephens et al, 2016).

Coastal storm inundation areas in the Auckland region were mapped in 2013 (Stephens et al, 2013) using a static level or 'bathtub' inundation-mapping technique. In this method, all land lying below the coastal storm inundation elevation is assumed to be flooded in its entirety if there is a direct flow path to the sea or harbour waters. The static inundation maps are created in a geographic information system (GIS) and do not fully capture the dynamic and time-variant processes that occur during a coastal storm hazard event (eg, through tidal fluctuations and flow paths).

The static method is efficient, which makes it useful for region-wide application (as per the 2013 Auckland study scope), and for risk screening, such as applied in Waikato Regional Council's coastal inundation tool (Waikato Regional Council, n.d). The static method is conservative because it tends to over predict rather than under predict inundation by the high-water period of storm tides that may last for one to three hours. The over prediction applies more for wider coastal plains, whereas for narrower coastal margins, the mapped inundation level will be much closer to the expected inundation extent.

Dynamic inundation modelling uses detailed numerical hydrodynamic models to simulate the incursion of the sea over the land surface. This is detailed, data-intensive, time-consuming and relatively costly work, which is easier to apply over small areas, where more certainty is required.

Parakai has a wide, low-lying coastal plain that is intersected by the Kaipara River above its confluence with the Kaipara Harbour. This was an area identified from the 2013 study where further sea-level data and dynamic inundation modelling could improve Auckland Council's understanding of coastal storm inundation.

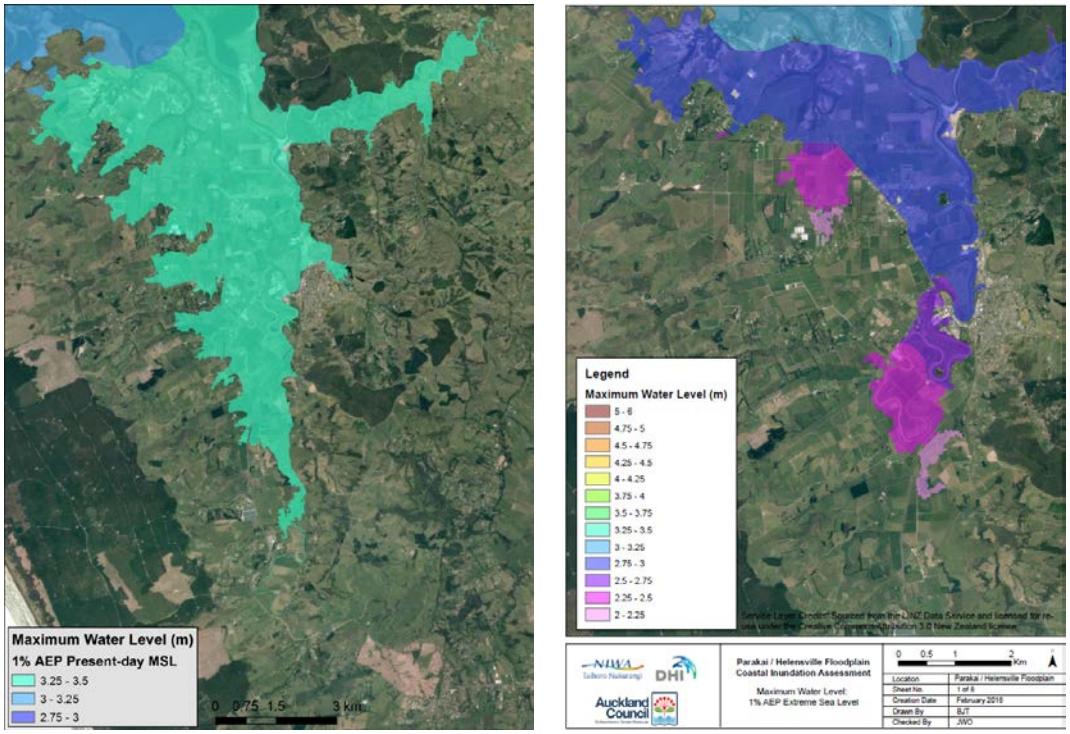
Figure 54 shows the difference in the 1 per cent annual exceedance probability coastal storm inundation elevations mapped using the static (Stephens et al, 2013) and dynamic (Stephens et al, 2016) methods. Both methods gave similar elevations at the confluence of the Kaipara River and Kaipara Harbour. The calibrated hydrodynamic model predicted considerable frictional attenuation, however, causing the storm tide elevation to drop inland, while no attenuation is modelled using the static GIS-mapping technique. As a result, the difference in predicted inundation elevation between the two methods increases inland. The dynamic model predicted water levels that were up to 0.5 metres lower than the static method over most of the seaward flood plain, and up to about 2 metres lower further inland. The total area of coastal storm inundation was predicted to be 60 per cent less using the dynamic modelling.

The original static inundation model of the area assumed local stopbanks that were identifiable in the topographic data were fixed structures. In the refined dynamic inundation model, the coastal inundation areas were considered independent of the presence of these structures, given their dynamic nature and potential to change over time. This maintains a degree of conservatism in line with the precautionary principles adopted by the Proposed Auckland Unitary Plan.

The difference between the static and dynamic methods was much less for the sea-level rise (SLR) scenarios: for the plus 1 metre SLR scenario, the total area of coastal storm inundation was predicted to be just 9 per cent less using the dynamic modelling, and both methods gave approximately the same results for the plus 2 metre SLR scenario. Large SLR will inundate the floodplain and fill the basin in which the Parakai–Helensville region is located. Dynamic frictional effects that hold back the flood wave at present-day mean sea level (MSL) (when the water is shallow) will be reduced after significant SLR (when the water is deep – assuming no change in the floodplain topography).

These results suggest that the static mapping method is likely to be adequate for risk-screening exercises or coastal hazard assessments using high SLR scenarios (associated with longer planning timeframes). The dynamic mapping method is best used for site-specific hazard assessments where high accuracy is required at the property scale and where smaller SLR scenarios are being modelled.

Figure 54: Comparison of static (left) and dynamic (right) maps of 1 per cent annual exceedance probability (AEP) coastal storm inundation at present-day mean sea level (MSL), Parakai, West Auckland



Source: Stephens et al (2016)

Case study E: Identification of areas potentially affected by coastal erosion (Gisborne District)

The Gisborne District coastline extends from Takararoa in the south to Omaruparoa in the north. It comprises some 138 kilometres of sandy and gravel beaches and 202 kilometres of cliffed coastline. This study first used a region-wide screening to identify those parts of the coast that could potentially be affected by coastal erosion hazards and to show these on maps at a broad scale. This information can now be used by the Council to identify areas along the coast where there are natural, built and/or cultural features that are of value and at high risk of being adversely affected by coastal erosion. Those areas of high risk can be prioritised for more detailed assessment of the effects that could occur.

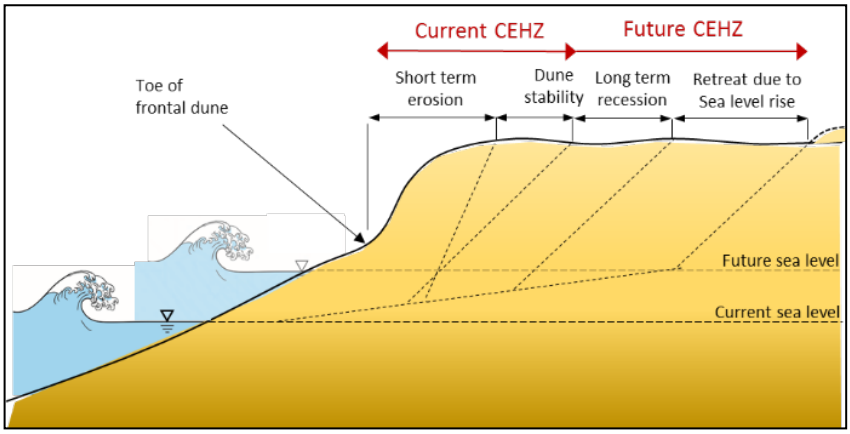
The assessment addressed the coastal hazards identified in Policy 24 of the New Zealand Coastal Policy Statement 2010 (NZCPS 2010) (Department of Conservation, 2010). The geomorphological character of the coastline was assessed using an aerial survey by fixed wing aircraft, and the coastline was categorised into unconsolidated beach and cliff coastal types, with conceptual models developed for each to describe the erosion processes. An area susceptible to, or potentially affected by, coastal erosion was assessed using similar methods to Gibb (1998) and Reinen-Hamill et al (2006). For unconsolidated beaches (figure 55), this included terms for:

- short-term changes in horizontal shoreline position related to storm erosion due to a singular or cluster of storm events
- dune stability allowance to allow for the collapse of over-steepened dune scarp following erosion
- long-term rate of horizontal coastline movement
- horizontal coastline retreat due to the effects of increased mean sea level.

For consolidated cliffs (figure 56), this included terms for the characteristic stable angle of repose, the historic long-term rate of cliff toe retreat and potential increase in future long-term retreat due to sea-level rise effects. Component values were derived from existing and new data, and hazards assessed over a 100-year timeframe. Offsets from a current shoreline were mapped continually around the coastline.

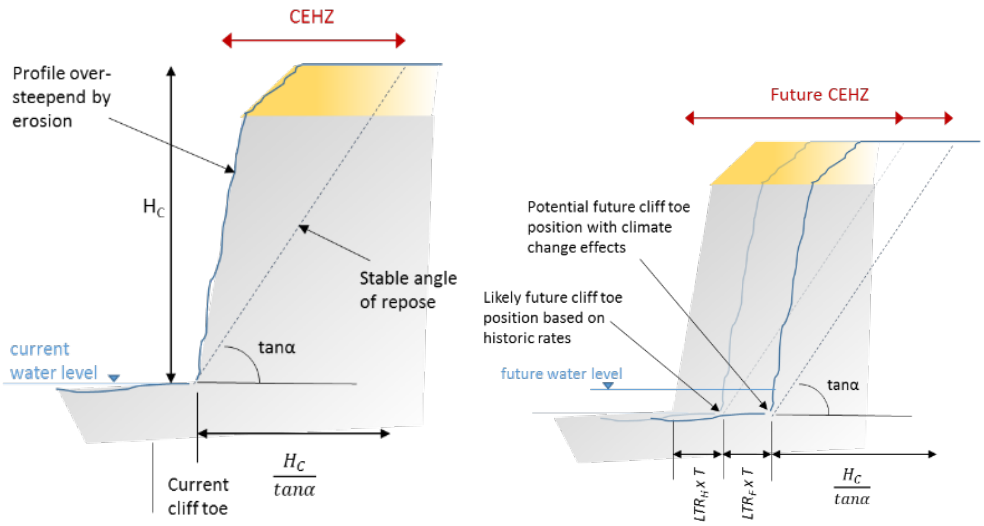
The building block approach of combining components typically produces a maximum hazard extent. This was considered suitable for identifying areas potentially affected by coastal hazard on a regional scale. The study used the continuing high emissions sea-level rise scenario (RCP8.5 median) allowing for local tectonic movements. This was considered appropriate for defining the potential areas affected by erosion hazard based on available national guidance (Ministry for the Environment, 2008a) but did not assess hazard for multiple scenarios or an upper-bound scenario as proposed in this guidance update.

Figure 55: Definition sketch for open coast coastal erosion hazard setback



Note: CEHZ = coastal erosion hazard zone. Source: Shand et al (2014)

Figure 56: Definition sketch for cliffed coastal erosion hazard setback



Note: CEHZ = coastal erosion hazard zone. Source: Shand et al (2014)

Case study F: Probabilistic coastal erosion hazard (Northland region)

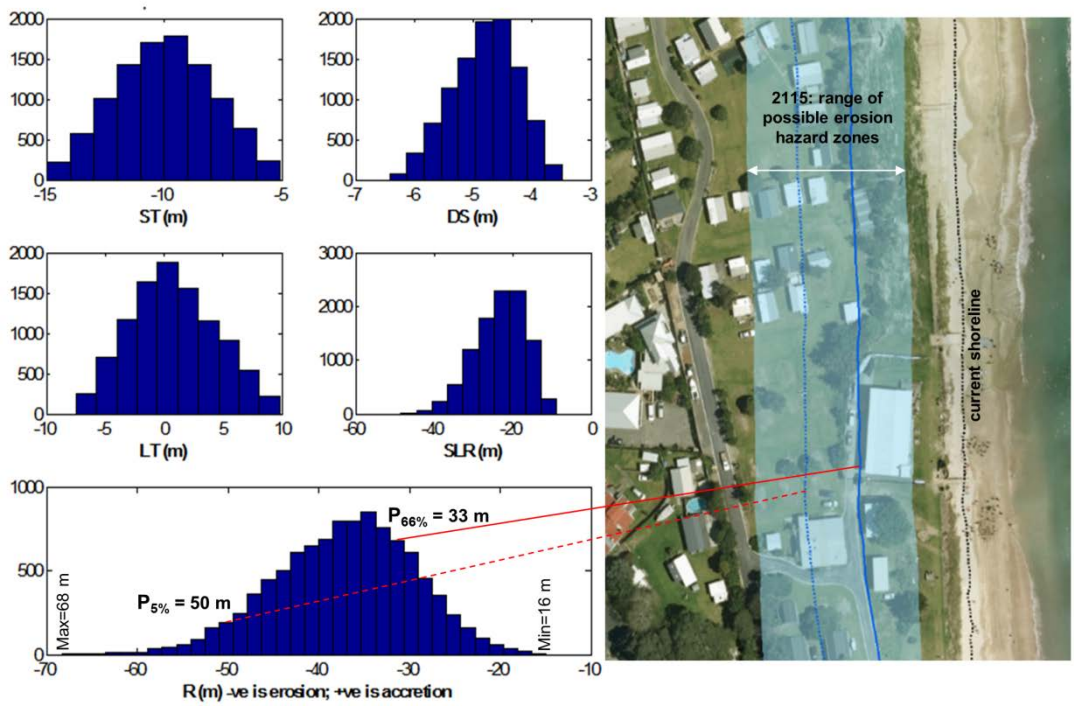
This project assessed and mapped coastal erosion hazards in detail for selected high-priority sites in the Northland region. A methodology was developed (Shand et al, 2014) that combined standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters, with new techniques for defining and combining parameter ranges to allow for natural variation and uncertainty in individual parameters (Cowell et al, 2006). The resulting distribution provided a probabilistic forecast of potential hazard zone width for differing likelihoods, in accordance with Policy 24 of the New Zealand Coastal Policy Statement 2010 (NZCPS 2010) (Department of Conservation, 2010), and supported by best practice guidelines (ie, Ramsay et al, 2012).

Models were derived for different coastal types, including unconsolidated beaches, hard and soft cliffs, and estuarine shorelines, with component values determined using statistical, empirical and numerical methods. Component ranges tended to be narrower where processes were more well understood or natural variation was small (ie, storm cut) and wider where processes were less well understood (ie, coastal response to sea-level rise (SLR)) or natural variation was high (ie, long-term fluctuations around river mouths). Multiple planning timeframes were applied to provide information on current hazards and information at sufficient timescales for planning and accommodating future development. The potential hazard zone was defined based on the probabilistic forecast (ie, figure 57), with coastal erosion hazard zone (CEHZ) values with a 66 per cent probability of being exceeded ($P_{66\%}$) and a 5 per cent probability of being exceeded ($P_{5\%}$) adopted as prudent *likely* and *potential* CEHZ values and mapped from the current shoreline as shown in figure 57 (Shand et al, 2014).

Due to the uncertainly of some components (ie, beach response to SLR), the output is a quasi-quantitative exceedance probability yet still provides valuable insight on the range and likelihood of potential hazard extent (figure 57), which improves the understanding of hazard risk. While certain likelihoods ($P_{66\%}$ and $P_{5\%}$) were selected for mapping, the method allows any other hazard likelihood to be defined and mapped. This assessment provided the CEHZ likelihood for a particular future SLR scenario (RCP8.5), using the scenario confidence bounds to define the SLR parameter range, rather than assessing the CEHZ for a range of potential scenarios as advocated in the current guidance update.

This guidance suggests modifying the method in future to more clearly separate the statistical and SLR scenario uncertainty. Thus, the robust statistical framework would still be applied for all components other than SLR, and the modelling would be undertaken using several distinct SLR scenarios. Alternatively, the present method could reasonably be applied for relatively short planning timeframes where there is reasonable agreement between the SLR trajectories for the various representative concentration pathways.

Figure 57: Example shoreline-change components as histograms in developing a coastal erosion hazard zone (CEHZ) (left) with the resultant width of possible CEHZ and $P_{66\%}$ and $P_{5\%}$ lines overlaid on an aerial image (right)



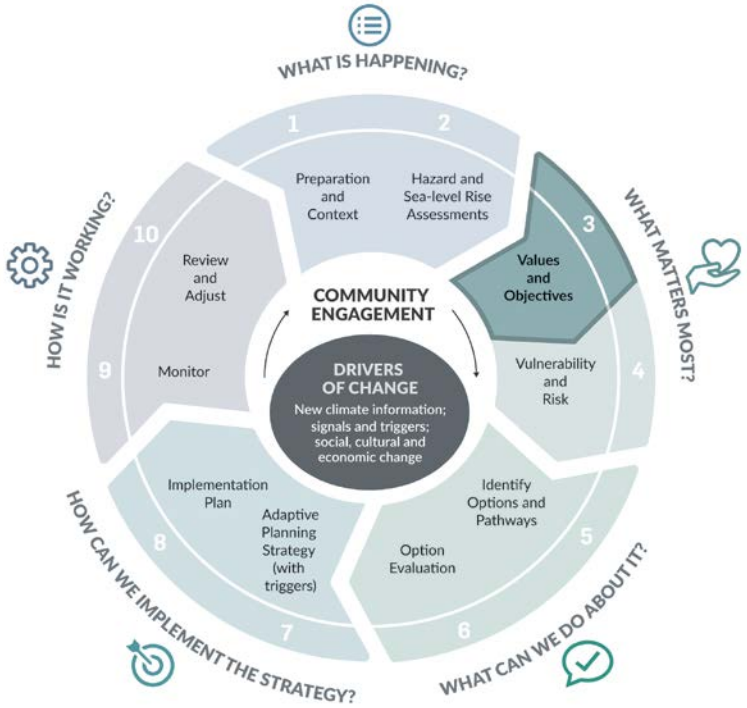
Note: CEHZ components (m): ST, LT = short-term and long-term shoreline change; DS = dune-stability factor; SLR = sea-level rise contribution to shoreline change; R = combined shoreline change used to set a CEHZ. Source: Shand et al (2014)

Section B: What matters most?

7 Establishing values and objectives

Chapter 7	**Chapter 7 covers:** • what community values are • exploring and identifying values with communities, iwi/hapū and stakeholders • case studies for determining community values • reframing community and cultural values into a set of objectives • developing local government objectives.
Step 3	**Key tasks** a. Identify who should participate in considering community values. b. Decide on what method should be used (table 16). c. Translate the information on community values into themes, then objectives. d. Identify local government objectives (district, regional, services council-controlled organisations). e. Collate and consolidate community and local government objectives to take forward into subsequent steps in the decision cycle.

Figure 58: Step 3 in the decision cycle: What matters most? – values and objectives



7.1 Break the ground

A range of values and objectives of coastal communities will be affected by coastal hazards and sea-level rise (SLR) in different ways. At step 3 of the decision cycle (figure 58), the values and objectives of the community, including those affected, need to be identified. This is necessary to enable what is important to communities to be identified and combined with the hazards assessment (step 2) to support a vulnerability assessment (step 4). It will also form the basis for evaluation as to whether options in step 6 meet the objectives sought.

The primary function of establishing a collaborative process to explore values and objectives is to develop a joint understanding of the problem, what is important and to whom, so objectives can be developed to guide the adaptive decision-making process. It will involve identifying and bringing people together in a process that facilitates dialogue, learning and trust building, and allows participants to understand the array of perceptions, values, interests and priorities in the community.

Understanding and capturing values and forming objectives can range from scoping studies to more detailed investigations to match the scale and detail in the hazard and SLR assessments (step 2) and the nature of the decision being made. Three stages are involved.

1 Exploration and capture of community, iwi/hapū and stakeholder values in a way that clearly expresses:

   a. What of value is potentially affected by coastal hazards and SLR?

   b. Who is it of value to?

   c. Where is it located geographically?

   This includes consideration by the council of the foreseeable needs of future generations (including services and infrastructure) and how communities could be affected in the future by decisions taken today.

   Questions that underpin this activity include: Who should participate? How could they participate? What tools and techniques could be applied to uncover community values?

2 Reframe the agreed community values into objectives for the different stakeholders (public and private) on the coast to enable inclusion in the vulnerability assessment and future adaptation decisions.

3 Clarify and agree on local government objectives over different jurisdictions and functions. Agreement will require multi-party multi-function discussion.

Using the three stages will allow decision-makers to understand the values the community, iwi/hapū and stakeholders have about their coastal environment and property, and their expectations of decision-makers for addressing them. Understanding these elements of the community will help the council gauge the feasibility of its adaptive plans at the implementation stage. Moreover, the decision-makers will need to have a clear understanding of their own joint objectives, role and obligations. This information then feeds into step 4 of the decision cycle for assessing the vulnerability and risk that overlay the hazard assessments with the values, objectives and consequences for assets and people to determine the vulnerability and risk profiles.

7.2 Who should participate?

The question of who should participate and how is introduced in chapter 3. When considering the community values and objectives (step 3), the processes selected (section 3.2.1) should be as inclusive as possible, interacting with a range of participants, and including different views, perspectives and knowledge sets.

7.3 What are the community values?

Once the hazard and SLR assessments are complete, it is necessary to engage with the wider community (community, iwi/hapū and stakeholders) to understand what 'things or objects' of value could be affected by increasing coastal hazards from the effects of climate change, in particular, on the back of rising sea level. These 'things or objects' may include physical items like land and buildings, roads, services and utilities and their level of performance (eg, 'three waters', drainage), parks and reserves, retail and commercial centres, recreational services, community assets, and more intangible elements like the ability to practice tikanga (Rouse et al, 2016), community cohesion and spirit, occupational identities, culture and historical sites (Barnett et al, 2016) (box 15).

A comprehensive understanding of what is important, and who it is important to, will underpin subsequent decisions about adaptation options and their implementation through time, their evaluation and future monitoring. Without this knowledge, community values are unlikely to be fully considered in consent, policy and adaptation decisions, thus risking community acceptance that decisions are legitimate. This can result in opposition to implementation of the adaptive plan. Investment of time and effort at step 3 of the decision cycle (figure 58) is more likely to result in successful outcomes from the adaptation decision-making process in later steps.

BOX 15: COASTAL COMMUNITY VALUES THAT COULD BE AFFECTED BY SEA-LEVEL RISE, COASTAL EROSION AND INUNDATION IN AOTEAROA-NEW ZEALAND

Private property and businesses

- Homes and businesses flooded
- Beachfront property at risk due to beach erosion or inundation
- Financial stability of community; property loss, compensation and insurance
- Land values – devaluation due to erosion or inundation
- Loss of productive land due to saltwater intrusion
- Loss of land holdings, farm stock and related economic opportunities

Local infrastructure

- Lifeline infrastructure and community facilities
- Stormwater and wastewater systems
- Access and safety of roads along the foreshore
- Cultural assets – marae, urupā, kura kaupapa

Community lifeways and recreation

- Community events
- Beach access for recreation and public use
- High tide sandy beach – loss due to erosion or coastal protection works
- Supplementing household supplies (and incomes) through hunting and harvesting of wild foods (eg, shellfish)
- Persistence, safety and usability of public coastal reserves and estuaries
- Sacred places and sites – degradation resulting in loss of identity, whakapapa and well-being
- Displacement of people

BOX 15: COASTAL COMMUNITY VALUES THAT COULD BE AFFECTED BY SEA-LEVEL RISE, COASTAL EROSION AND INUNDATION IN AOTEAROA-NEW ZEALAND

Ecology and biodiversity

- Coastal habitat, potential to lose certain species
- Rare species (ie, New Zealand dotterel)
- Degradation of ecology leading to loss of traditional knowledge about species and harvesting techniques
- Adverse impacts on mahinga kai and whānau health from damage and destruction of sewer lines and septic tanks
- Human–environment relationships and well-being
- Saltwater intrusion (salinisation) into freshwater resources

Aesthetics

- The natural appearance of the beach, estuary and surrounding landscape, especially if hard engineering solutions are enacted
- Affect the appeal of the area as a nice place to live, affect 'community feel'

Source: Rouse et al (2016)

Four broad categories of methods can guide processes in step 3 and can be used in combination, depending on the scale of the process planned (table 16). Each has its advantages and disadvantages.

Table 16: Four categories of methods that can be applied to gain an understanding of community values

Methods	Description	Examples
Interrogate existing documents	Explore and examine what values are already documented, eg, iwi/hapū management plans, iwi/hapū natural resource management plans, community outcome documentation, surveys, reports **Advantages**: Scoping existing knowledge around values and conflicts avoids repeating questions and provides context for future engagement. **Disadvantages**: Things change and will need to be verified through subsequent methods.	Section 3.2.2
Surveys	Postal, internet-based or telephone surveys can be undertaken to ask participants about their values, what they value and their objectives for addressing coastal hazards and climate change impacts. **Advantages**: Can obtain information from a large number of participants at a wide scale (eg, regional); raise awareness of the issues; obtain input from a range of participants. Low cost. Identify key issues that are critical at a regional scale. **Disadvantages**: Low levels of detail on specifics (superficial data), response rates can be low and represent particular demographics, little opportunity for learning, discussion or interactions. Risks missing key information.	Section 7.3.1

Methods	Description	Examples
Key informant interviews	Interviews with key groups and individuals in the community (iwi and stakeholders) **Advantages**: Obtains a good level of detailed information on relevant topics. Obtains views of those who are not comfortable contributing in other forums. **Disadvantages**: Interviewing key individuals who represent the different groups is essential. May miss sections of the community. No opportunity for participants to listen to or learn from other participants or groups.	Blackett et al, 2010a; King et al, 2011, 2012, 2013; Schneider, 2014
Meetings and hui	Public meetings, hui or other events (eg, open days, field days) can be organised to discuss the issues. **Advantages**: Can apply a number of participatory data collection methods in this setting. Suited to the local scale, listening and learning can be built in. **Disadvantages**: May miss sections of the community who cannot attend. Careful organisation of the event (timing and the way the event is held) will be required to ensure balanced dialogue.	Blackett et al, 2010b; King et al, 2011, 2012, 2013; Rouse and Blackett, 2011; Rouse et al, 2011, 2013

The outcome should be a summary of community values.

- What values and things of value are likely to be affected by coastal hazards and SLR?
- Where are they and who are they valuable to?
- What is the diversity and (dis)agreement of values and norms?
- To what degree will groups in the community be affected?

Some societal groups are likely to be more adversely affected than others by coastal hazards, SLR and adaptation decisions taken (Local Government New Zealand, 2016b). This is why it is critical to ensure the values of all social groups are highlighted and considered when assessing risk and identifying and evaluating adaptation options and pathways over time.

7.3.1 Examples and case studies

Use of surveys

Surveys are a helpful tool for understanding either regional scale scoping of what is important and valued or local scale information to complement and support a collaborative process. They can be an effective mechanism to obtain information and insights on people's views, perspectives on coastal management and values associated with the coastal environment. Surveys are classified as a technique to compile input in the International Association of Public Participation (IAP[2]) toolbox. A number of surveys have been undertaken in New Zealand in coastal management contexts (Johnston et al, 2003; Berg and Pettersson, 2004; Stewart et al, 2005, 2007, 2010; Becker et al, 2007).

Rouse et al (2016) draw four conclusions from the available New Zealand survey data.

1 Results suggest that climate change and SLR are generally viewed as temporally distant threats that will impact on coastal communities and property through coastal erosion, flooding and drainage issues.

2 Risks are more keenly felt by those who are already experiencing them. Those who live further away from the beach, or have not experienced an event, do not think they will be affected in the near future.

3 Views on management options tend towards hard engineering solutions, with the exception of areas where beach renourishment or dune replanting have already demonstrated benefits. Support for managed retreat appears to be highly variable across the country.

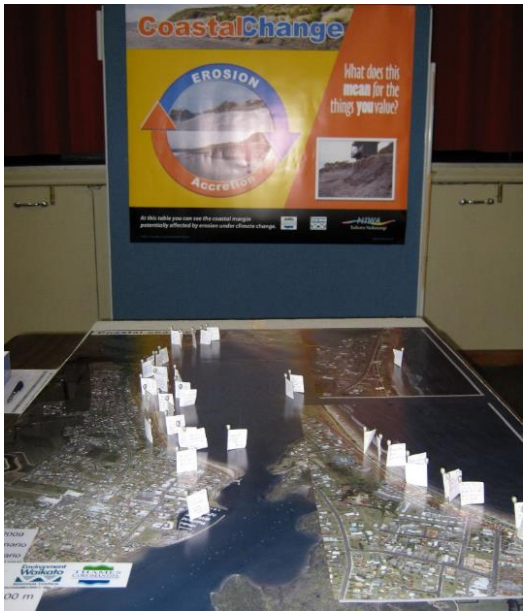
4 There is a high level of geographical variation in perception and views of risks and coastal management options, indicating that each community is unique and should be approached as such.

These surveys can provide a starting point for survey design and a set of reference data, but they will not replace the need to collect specific local data. Once collected and analysed, survey data can provide a way to deepen the understanding of different groups, ensure wide representation and cross-validate data sets.

A visual process to determine what a community values: Whitianga example

In 2010, in the coastal township of Whitianga, an open day on the potential impacts of climate change on the community was held in a hall near the main shopping centre. One of the purposes of the event was to get spatial details on what the community valued that could potentially be impacted by SLR, coastal inundation and estuarine vegetation change. This was achieved through the use of large A0 aerial photos on which participants located (using pinned flags and text) what they valued within the community and surrounding area (figure 59).

Figure 59: Value flags placed by community members on polystyrene A0 boards showing potential coastal erosion and change on a high-resolution aerial image



(Credit: P Blackett – Whitianga open day, 2010)

This process was facilitated by the research team (including regional and district council staff), who asked further questions and talked with participants about their concerns. Each participant was able to add their own thoughts and read those of others, which generated discussion and quickly identified shared concerns. All the information was preserved in its original form and captured as a geographic information system layer (Rouse et al, 2011, 2013; Blackett et al, 2010b). Values were grouped using a thematic analysis and could be used to underpin the formation of objectives.

Variations could include setting up maps at community events, on the street outside busy locations (Cinderby, 1999, 2010; Cinderby and Forrester, 2005; Cinderby et al, 2008), online, during an interview, or in a workshop/hui setting. Locations for engagement should be

selected to maximise the diversity of potential participants and interact with parts of the community traditionally difficult to connect with. Although effective at the local scale, application at the regional scale could require the maps to be deployed multiple times or with regional representatives.

Examples of place-based Māori coastal adaptation

Many iwi/hapū environmental or natural resource management plans detail climate change issues and implications, and these should be read before more detailed conversations with local iwi/hapū (as cited in Rouse et al, 2016; section on Māori community adaptation and vulnerability).

A number of place-based studies regarding Māori coastal community adaptation have been undertaken recently (King et al, 2011, 2012, 2013; Manning et al, 2011, 2015). Each study combined future scenarios of coastal hazards under climate change and SLR with a discussion of exposure, impacts and how each community was positioned to respond (adaptive capacity). Hui and interviews involving whānau and Māori research scientists were the primary forum for the evolution of these conversations.

In an example from Manaia, Settlement, Hauraki-Waikato (King et al, 2012), the effect on iwi, hapū and whānau by coastal climate change and related socio-ecological changes was summarised into four key intertwined themes. These influences affect the ability of the community to deal with climatic risks (paraphrased from King et al, 2012, p 7):

- the unreliable state of lifeline infrastructure and housing and the insufficient finance and resourcing to adequately reduce exposure and sensitivities associated with climate affected hazards and stresses
- the role of social–cultural networks and conventions in coping with impacts and adaptation. The social networks of whānau and cultural values and approaches centred around tikanga (conventions, culture, custom, correct procedure, lore), whanaungatanga (relationships, connections), kotahitanga (solidarity, unity, collective action) and aroha (sincerity, mutual respect, love) were often referred to as the Māori way of dealing with hazards, risk and human–environment well-being. Such principles and regulators of community behaviour, however, depend not only on the relationship between whānau and hapū but also on the relationship between people and the environment – which is supported through regular interaction and the complementary principles of rangatiratanga (control and jurisdiction) and kaitiakitanga (stewardship, respect, guardianship). The value of quality external relationships (formal and informal) with other iwi, wider community groups and government organisations and authorities was also emphasised as important for helping to meet the emerging demands of increasingly complex social, economic, political and bio-physical system changes facing the community
- the importance of Māori knowledge (eg, traditional activities and practices) in knowing about environmental change and risk. In parallel, gaining new knowledge and skills through traditional education to facilitate the ability to draw on multiple forms of knowledge
- institutional and legislative influences were also recognised as having a determining impact on iwi/hapū and whānau well-being and development and the ability to adapt to a changing climate. For example, equitable representation in local planning and resource management arrangements, the nature of participation afforded to the community in social as well as environmental policy development and decision-making, and the even deeper challenge of competing human–environment values, beliefs and behaviour, which for participants were inseparably linked to ethics surrounding the integrity of life and the responsibility to future generations.

It is evident from this work how intertwined adaptation is with other socio-ecological challenges and cultural knowledge and practices. Consequently, conversations with iwi/hapū and whānau regarding adaptation and values will touch on many subjects, all of which will be necessary for understanding what is important for enabling adaptation. Additional studies that seek to strengthen the capacity and capability of iwi/hapū, whānau and Māori business to deal with climate change impacts, risks and adaptation, are now under way as part of the Deep South National Science Challenge (National Science Challenges, n.d). These will be available in the next few years.

Many of these case studies are using a Māori-centric (kaupapa Māori) approach to climate change adaptation and will represent a critical step forward in iwi/hapū, whānau and Māori agribusiness.

7.4 Reframing community values as objectives

Once 'what is valued' by the community has been articulated and explored, the material can be aggregated, where possible and appropriate, into common themes (Kitchin and Tait, 2000; Flick, 2009). Each theme can be named and restated as an objective (table 17), which will help to facilitate integration of community values with local government statutory objectives and obligations. More importantly, the objectives provide guidance on what needs to be included in future plans and adaptation planning. There will be a number of objectives, each relating to a different theme.

Table 17: Two examples of translating values into objectives

Theme: public access to greenspace	
What is valued by the community	**Translated objective**
Public recreational space for picnics and family activities Safe playgroups for children to play Aesthetic Greenspaces along the foreshore Close proximity and easy access to parks and reserves	Maintain safe, aesthetically pleasing, public greenspaces (including picnic and playground facilities) along (or close to) the foreshore and distributed throughout the community
Theme: biodiversity and ecology	
What is valued by the community	**Translated objective**
Presence of native coastal species Presence of rare species (ie, New Zealand dotterel) Functional viable coastal ecosystems Mahinga kai species present and able to be safely taken (eg, no health risks)	Ensure a functioning coastal ecosystem that supports rare and mahinga kai species

Source: Rouse et al (2011, 2016)

The translated objectives can help inform adaptation options. For example, one of themes generated from the community in Whitianga, is the importance of parks and greenspaces that are of value for a variety of reasons (table 17). Thus, it is important to consider how parks and reserves will be affected, where future park and reserve facilities could be located and how they could be designed to serve multiple functions. As an example, a valued park could be lost to increasing coastal hazards and SLR, but a replacement, which meets the community objective, can be factored into the adaptation planning process.

The underlying richness and detail of the original compilation of values should also be retained for reflection throughout subsequent engagement processes.

7.5 Local government objectives

Given the multiple roles and different jurisdictions of local government, a cross-organisation cross-function discussion (table 18) will help with identifying and consolidating objectives across a region or district. Clear descriptions of local government objectives across different activities and scales inform subsequent adaptation planning steps.

Table 18: Key questions to address when generating local government objectives

Key questions	Supporting questions
Who needs to be part of the conversation?	Who has jurisdiction in this area? What are the relevant functions that need to be represented? Who can represent the key groups? What and who is missing? Are other council-controlled organisations and non-council organisations needed as part of this discussion?
What are the different objectives across the local government jurisdictions?	What plans and policies exist? What goals and objectives exist and why? Are they aligned?
What are the different objectives across the local government functions?	What plans and policies exist? What goals and objectives exist and why? Are they aligned?
What are the set of agreed objectives?	How can the most important objectives be identified? How can any misalignment be addressed? What are the implications and consequences of the set of agreed objectives within local government and external organisations?

7.6 Collation of community and local government objectives

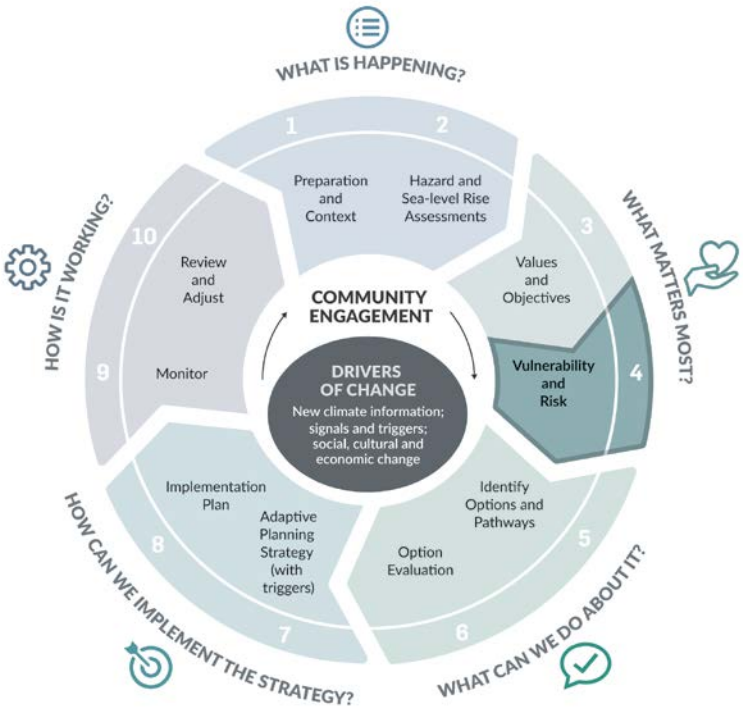
Clear statements of local community objectives, alongside local government objectives, provide an opportunity to look for co-benefits across jurisdictions and sectors and to manage expectations. For example, the community desire for parks can be aligned with the council's objective to protect buildings from inundation events with a particular annual exceedance probability, and provide for recreational areas. Areas where building should be avoided can be used as public space, provided adequate mechanisms are in place to protect the public during future hazard events. Clear articulation of community and local government values and their translation into objectives is crucial because they will inform and guide the identification of options and pathways in step 5 and underpin the development of measurable early signals and triggers (decision points) in section 10.1.1 (figure 70).

Chapter 2 outlines local government processes where such objectives around adaptation can be formalised (eg, council long-term plans).

8 Vulnerability and risk

Chapter 8	**Chapter 8 covers:** • what vulnerability assessments are and their guiding principles • risk assessments: guiding principles and dealing with likelihood • how to sequence risks assessments at different scales and steps • engagement for assessing vulnerability and risk • dealing with differences in views on values, risk and scientific information.
Step 4	**Key tasks** a. Scope out a vulnerability assessment for coastal communities, eg, scale, information needs, determining sensitivity to climate change and coping capacity of the system(s). b. Set up the sequence of three levels of risk assessments for different scales and steps, and what risk assessment method is to be used. c. Determine how communities, iwi/hapū and stakeholders will be engaged working collaboratively on results from vulnerability and risk assessments.

Figure 60: Step 4 in the decision cycle: What matters most? – vulnerability and risk



Vulnerability and risk assessments (step 4) build on the sea-level rise (SLR) and coastal hazard assessments completed in step 2 and the identification of community and stakeholder values and objectives in step 3 (figure 60).

Step 4 will assess the predisposition to be adversely affected, arising from exposure to coastal hazards and ongoing SLR. This includes assets, people and the things they value (ie, sensitivity to hazard exposure), and also the fragility of public and private assets

(eg, infrastructure) to hazard exposure. The adaptive capacity[83] of the community and supporting services and infrastructure is also another key aspect of vulnerability that augments risk assessments. A mix of vulnerability and risk assessments is described here.

8.1 Vulnerability assessment

Vulnerability is defined as the predisposition of a human or biological system to be adversely affected. It thus includes the concepts of sensitivity to harm and lack of capacity to effectively cope and adapt (IPCC, 2014c).

In an engineering and asset context, vulnerability is used to mean 'fragility' where, for a given hazard exposure, it is a measure of the physical or financial integrity of buildings, infrastructure or individual assets to perform under hazard exposure and the extent of resulting disruption or reduced levels of service to people. Here, vulnerability is also a component of assessing risk, with consequences quantified by overlaying the hazard exposure, the assets and their vulnerability (eg, RiskScape, NIWA and GNS Science, n.d; Schmidt et al, 2011).

This guidance uses both definitions. Vulnerability assessments (VAs) are used worldwide to assess the impacts and implications of coastal climate changes. The main function of these assessments is to process and overlay the hazards, values and objectives information with the asset fragility, sensitivity and adaptive capacity information for the following purposes in the decision process:

- aggregating information and projections for assessing impacts, implications and adaptive capacity across a wide range of socio-economic, social, environmental and infrastructure domains at national, regional, district and city scales (step 4 in this guidance). Also supports application of Policy 24 and 25 of the New Zealand Coastal Policy Statement 2010 (NZCPS) (Department of Conservation, 2010) to identify areas 'potentially affected' by coastal hazards over at least 100 years
- as an input to comparative ranking processes for the parts of a district, city or region of the consequences of the climate change for coastal areas (steps 4 and 5)
- as an input for prioritising identified exposed areas (including sectors, services, settlements or environments) at 'high risk of being affected' (Policy 24, NZCPS 2010) and areas of existing development 'likely to be affected by coastal hazards' (Policy 27, NZCPS 2010)
- as an input for identifying adaptation thresholds for the onset of coastal hazard risk consequences, or triggers for activating decision points when adaptation settings need to be reviewed and adjusted (eg, triggers could be the number of nuisance events that stretch coping capacity, expressions of tolerability or acceptability limits or signs of stress on valued coastal ecosystems and their services).

VAs are used by the climate change adaptation community to order, index and prioritise information on impacts and implications of climate change. They are typically either top-down or bottom-up. Top-down VAs use climate change scenarios for a range of drivers (eg, temperature, rainfall, SLR) over different planning timeframes to generate climate change exposure maps, indexed to a vulnerability scale, across socio-economic, environmental and social and cultural domains.

[83] Adaptive capacity is defined as the resources available for adaptation to climate change and variability or other related stresses, as well as the ability of a system to use these resources effectively in the pursuit of adaptation.

A coastal environmental example for New Zealand (figure 61) is the coastal erosion and coastal inundation sensitivity index to coastal climate change, which weights various contributing factors to coastal erosion sensitivity (eg, sediment type, coastal landform, hinterland type, tidal range to SLR ratio, wave exposure and future changes in hazard drivers (Goodhue et al, 2012)).

Figure 61: National sensitivity index for coastal erosion due to climate change

Assumes sensitivity is from a present-day zero baseline, that is, does not include historic or recent erosion or accretion trends. Source: Goodhue et al (2012)

On the other hand, bottom-up VAs develop vulnerability tables or maps that typically assess human and community coping capacity and distributional impacts (including on place-based values), using community participatory or co-production processes, following methods outlined in chapter 7 of this guidance.

Vulnerability assessment is essentially a sensitivity assessment to the potential harm and loss caused by ongoing sea-level rise. It includes the effects of a rising sea at the coastal margins and inland as groundwater rises as a result, and in combination with events such as coastal storm inundation and associated erosion. It includes an assessment of the region's or sector's sensitivity to such hazards, whether felt as an ongoing change in the physical conditions (eg, rising sea) or as events (eg, flooding of roads and assets from a storm, or a sandspit breach). VA also considers the ability or capacity to cope, recover and adapt (eg, address reducing asset performance, alternative road routes, houses higher on perimeter foundations, building materials, ability to move away from harm, social capital and networks). VA can also assess primary, secondary and indirect impacts (effects), for example, SLR and erosion at a beach resort leads to loss of intertidal beach amenity and a downturn in visitors to the adjacent town, which in turn leads to economic losses to businesses and related loss of the things people value.

As such, the term 'vulnerability' is used in this guidance to include assessment of the adaptive capacity of people, institutions and organisations. It also includes, for example, the 'fragility' of buildings, infrastructure or individual assets to perform under increasing hazard exposure (eg, a concrete building will be more flood resistant than a wooden building for the same slab-on-ground foundation), the numbers of people disrupted, time for repairs and recovery after each event, casualties and business or civic disruption.

For VAs, both sets of information are required to assess risk and evaluate options and pathways in step 6 (chapters 9 and 10) and develop the adaptive strategy and implementation plan (steps 7 and 8).

A regional approach to vulnerability and risk assessment in the first instance creates a consistent framework within which response options can be identified and evaluated (see chapter 10). It also provides an opportunity to coordinate coastal hazard risk management, given that it traverses local government jurisdictions. This creates opportunities for more efficient use of resources and thus co-benefits to communities. The steps in a VA follow.

8.1.1 Guiding practice: Steps in a vulnerability assessment

Guiding practice: Steps in a vulnerability assessment

The vulnerability assessment (VA) will draw on the hazard and sea-level rise (SLR) assessments conducted at step 2 of the decision cycle (chapters 5 and 6). Three main steps are involved in a VA:

1. a sensitivity analysis for the systems associated with the planning area including climate change impacts relevant to meeting the objectives e.g. sea-level rise for the four scenarios
2. an evaluation of the adaptive capacity of the system. Adaptive capacity will be determined by different characteristics of communities, organisations and their institutional frameworks. Measurable indicators of these will be developed at steps 6 and 7
3. an assessment of how vulnerable the system is to the effects of climate change.

Sensitivity is the degree to which a built, natural or human system is directly or indirectly affected by a given hazard exposure, and the changes in climate conditions that result in climate impacts on built and natural systems, for example, SLR as a result of projected climate change.

Adaptive capacity is the ability of natural and human systems to accommodate changes in climate impacts with minimum disruption or additional cost (recognising that SLR is ongoing and transitioning from the coast is inevitable for some areas).

Scope and scale of the assessment should be commensurate with answers to the following questions.

- What questions do you want answered by the VA?
- Which specific decisions do you want the VA to support?
- Where spatially do you want to focus the VA?
- How much capacity and information do you have for the VA, and who will manage and conduct it (eg, in-house or a contractor)?

Analysis of the level of sensitivity of the planning area can focus on the following questions.

- How exposed is the system to the hazards and climate change impacts (as defined in step 2, hazards and SLR assessments)?

- Is the system already stressed (eg, regular overtopping of a seawall or erosion of the coastal area)?
- Does the system have limiting factors or inflexibilities that could be affected by climate change impacts (eg, ability to adapt the system of concern)?
- Is the natural ecosystem at the lowest level of its range or subject to coastal squeeze (eg, protected nesting birds on beaches, Ramsar site,[84] wetland or marshes)?
- What is the impact threshold for the system of concern (eg, the operating range in a gravity stormwater system, height of a sea wall, width of a natural buffer zone)?

Analysis of the adaptive capacity of the planning area can focus on the following questions.

- Can the systems and people in the planning area accommodate the changes in climate impacts (eg, high numbers of elderly and young people, pre-existing stress due to economic conditions, location of critical and government and education facilities, state of existing protection, value of assets at risk, dependence on drainage systems)?
- Are there barriers to a system's ability to accommodate changes in climate impacts (eg, recognising that planning rules will most likely have been based on historic climate conditions or create other limitations on changing land use, citizens' sense of place, citizens' ability to adjust, cost or lack of insurance)?
- When does the rate of change go beyond the adaptability of the systems in the planning area (eg, beyond the ability of institutions (district plans, building consenting) and organisations (emergency management systems and councils) and people affected to respond (egress during events and relocation of houses))?
- Are there efforts already under way to address the impacts of climate change in relation to the systems and people in the planning area (eg, preparedness, criteria for monitoring the effectiveness of current planning approaches and early signals and triggers when a change of course is needed)?

The sensitivity and adaptability steps can be combined to determine how vulnerable the system in the planning area is. This process can be done either qualitatively or quantitatively.

The VA will not be static. Existing vulnerabilities will change as a result of the frequency, intensity, duration of impacts and the emergence of new threats and information. Implementation of response options will also change the vulnerability settings, as will changes in population, economic conditions and community preferences. Monitoring of all changes will be part of the monitoring strategy, as set out in chapter 11.

[84] Sites designated under the Convention on Wetlands (Ramsar Convention), which is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

8.2 Risk assessment

Risk is widely understood to mean *likelihood x consequences*, and this meaning is embedded in standards documents worldwide and consequent practice. In the international standard AS/NZS ISO 31000:2009, however, risk is also defined as "the effect of uncertainty on objectives".

Risk assessments couched in terms of the likelihood of consequences have diminished utility in the situation of a continually changing state, for example, where SLR will continue to rise for several centuries and at uncertain rates and magnitude, while social conditions are also changing at global, national and local levels. In this situation, the 'likelihood' side of the risk coin cannot be readily or reliably quantified, for SLR in particular, because plausible rises will be certain to occur – it is just a matter of the rate at which it occurs and when a given elevation is reached. There are also uncertainties about when the SLR will impact on groundwater hydrology.

Furthermore, risk 'heat maps' or matrices of likelihood versus consequences are too coarse to be useful for adaptation planning, because the likelihood score will invariably gravitate to the 'virtually certain' category (eg, Center for Science in the Earth System, 2007), as sea level continues to rise (ie, a matter of when), and reflect a timebound view of risk. This will also occur for coastal hazards, for example, coastal storm inundation may be rare at present (1 per cent annual exceedance probability (AEP)), but with a SLR of 0.5–1 metre, such an event will exceed the same elevation on every high tide (Stephens, 2015). So likelihoods around risk in this guidance are expressed as a bracketed time period of emergence of risk for an increment in SLR (chapter 5) or an increased frequency of a coastal hazard event for a specific SLR or range (chapter 6).

Risk assessment in an asset management context also needs to incorporate the risk to levels of service as well as physical damage to the component parts. Gibbs (2015, p 209) comments:

> …how consequence is defined, measured and used in risk assessments needs to be based … on the consequences to the levels of service that the asset is expected to deliver. In the majority of cases, services are delivered by multiple assets and hence each asset does not solely deliver one service in some instances. This is why organisations responsible for delivering services that require multiple assets are constantly changing, renewing, updating and de-commissioning assets in an attempt to better optimise service delivery in response to changing external forces. This focus on scale of the organisational service required to be delivered, rather than on individual assets themselves, is consistent with the new international standard for asset management, ISO 55000. In this light, it is possible that … small assets, such as critical pump stations for water supply, may actually play a role that is more critical than the size of the asset may suggest.

This nuance of risk assessment for adaptation planning in any coastal areas was recognised by guidelines produced by the City and County of San Francisco Sea Level Rise Committee (2015, p 18):

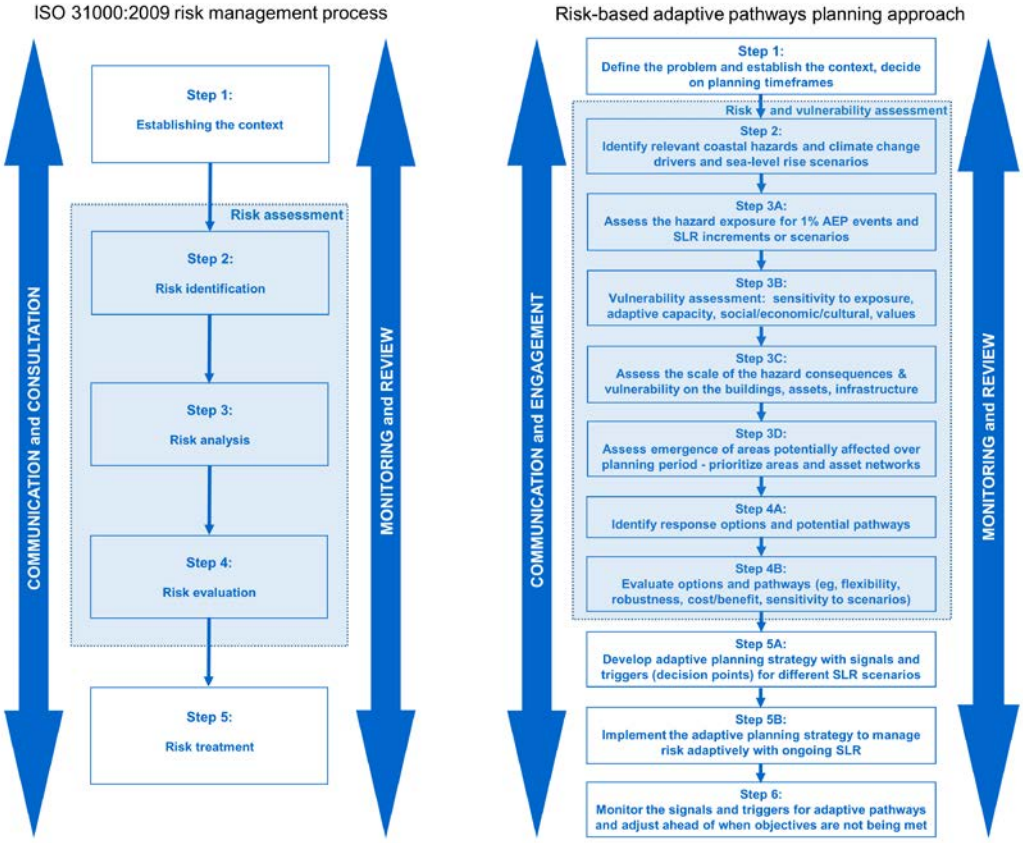
> When assessing the risk associated with sea level rise vulnerabilities identified through the vulnerability assessment, the most important component of classical risk assessment methods is the evaluation of consequence. Calculating the consequence of failing to address sea level rise for a particular asset or project is useful in prioritizing assets for adaptation planning. Consequence considers the magnitude of the impact that would occur under the selected sea level rise and storm surge scenarios. Information about the asset, such as its age, condition, and materials are often informative when considering the consequences.

No single measure of risk exists that can be used for all impacts of climate change and, in any case, the measure used will be timeframe dependent. Some measures can be quantified in part, for example, inundation damage using cost information, repair costs and recovery timeframes, and community, business and traffic disruption. Others, however, cannot, for example, the future rate of SLR, for which a suite of scenarios is needed to explore the risk sensitivity and timeframes for the inevitable emergence of damaging or disruptive consequences.

Some impacts will affect some groups in society more than others, while some may benefit. This means assessments of vulnerability and risk will need to consider and map linkages across multiple dimensions: economic, social, cultural and environmental consequences for a range of future coastal scenarios. This also means different risk metrics will be required, including quantification, and expert and community elicitation, using scenarios and narratives.

An outline of the steps required to assess risk and vulnerability in the context of a changing climate state is shown in figure 62, drawing comparisons with the generic steps in risk assessment in the AS/NZS ISO 31000:2009 risk management standard. The equivalent risk evaluation, risk treatment and monitor and review steps in the risk management process are covered in following chapters and steps 5–10 of the decision cycle (figure 1).

Figure 62: Equivalent steps in this guidance (right) compared with the AS/NZS ISO 31000:2009 risk management standard (left), focusing on risk and vulnerability assessments (shaded areas)



Note: Step numbers correspond with those in the risk standard framework on the left. AEP = annual exceedance probability; SLR = sea-level rise. Graphics: NIWA

8.2.1 Guiding principles and practice for risk assessments

Guiding principles for risk assessments

The following principles are recommended to guide vulnerability and risk assessments.

- Define the problem and set the objectives.
- Consider the impact of uncertainty explicitly, and areas 'potentially affected', as well as 'likely to be affected' by coastal hazard risk (New Zealand Coastal Policy Statement 2010, Department of Conservation, 2010), using sensitivity testing for a range of scenarios for the future.
- Risk based: where possible, follow standard infrastructure or asset risk assessment frameworks and terminology, but undertake stress testing of the location of assets for achieving service level performance to account for the irreversibility of sea-level rise and the effect on redundancy considerations.
- The changing nature of climate change risk profiles needs to be factored into risk assessments (and when comparing with other natural hazard risks).
- Adaptation (risk-reduction and avoidance) actions developed after risk assessments should be prioritised according to future performance of service levels of systems and networks (including roads) at the appropriate scale, rather than focusing too much on vulnerability or consequences of climate change to individual assets or properties in isolation.

Guiding practice: Sequence of risk assessments

To support different goals, data and resource availability of organisations, a three-level risk assessment process (of increasing depth and resource requirement) can be used (NCCARF, 2016).

- A first-pass risk screening can be conducted as a desk-top study to screen the climate change related exposure using readily available datasets. This will inform whether a more detailed second- or third-level assessment is required, or not (if the emergence of coastal risks are some way off compared with other locations).
- A second-pass risk assessment takes a standard risk-based approach using national data, regional and local information (input from hazard assessments for various sea-level rise scenarios or increments (chapter 6), demographics, asset attributes) and expert knowledge. It enables identification of how climate change may compound existing risks or the emergence of new ones and informs whether a more detailed third-level assessment is required.
- A third-pass (detailed) risk assessment process enables further investigation of short-listed risks and enables prioritisation and testing of strategies and actions in conjunction with the vulnerability assessments.

Risk assessments are needed at three steps in the decision cycle (figure 60).

1 At the end of step 2, to prioritise and inform council stakeholders, iwi/hapū and coastal communities, by undertaking regional and district risk screening following the hazard assessments (step 2). This will identify areas of greatest risk from sea-level rise and the regional and district extent. This high-level risk screening process can also inform regional

policy-making to avoid increasing the risk from redevelopment or change in land use (eg, intensification, greenfields, urbanisation) to give effect to Policy 25 of the NZCPS 2010 (Department of Conservation, 2010).

2 At step 4, more detailed risk and VAs can then be applied to areas with the highest and/or earliest onset of potential risk from the initial hazard- and risk-screening exercises. These should initially focus on areas where significant vulnerabilities and risk emerge at a modest SLR, as well as assessing the regional and district extent of risk, for example, on transport networks, parks and reserves, stormwater and drainage networks and ecosystems services.

3 Later, at step 6 (chapter 9), detailed risk assessments are an integral part of evaluating the effectiveness of response options in reducing risk, and under what conditions and bracketed time periods they remain effective.

Guiding practice: Risk assessment with a focus on consequences

The evaluation of risk by focusing on consequences under different sea-level rise (SLR) and coastal hazard scenarios (including sensitivity analyses for waves and storm surge) is recommended for New Zealand coastal areas. For consistency, the suite of hazard-assessment simulations or results from a range of SLR scenarios or SLR increments (from chapter 6) should be the same cases (or a subset) used as input to the risk assessments.

Quantitative risk assessments rely on good information or metadata on the attributes and locations and elevations of the exposed assets, people and property, infrastructure and utilities, and critical or government facilities. Two examples are:

- using RiskScape,[85] which was used for the national coastal risk-exposure study (Parliamentary Commissioner for the Environment, 2015) and can be used for detailed risk assessment or for assessing the effectiveness of response options to reduce risk (eg, used to evaluate river–flood reduction options and Avon central business district precinct rebuild options for Christchurch).
- the regional coastal risk screening for southern Hawke's Bay undertaken by Tonkin+Taylor (2016b).

In these risk applications, the 'likelihood' aspect of risk is linked to simulating a suite of SLR scenarios with coastal hazard extreme values (eg, 1 per cent annual exceedance probability (AEP)), as discussed in chapter 6.

RiskScape essentially overlays hazard exposure for various scenarios (percentage AEP inundation level or erosion added to SLR scenarios) over the inventory of assets and resident population of a region, district or city or at the suburb level, using fragility or vulnerability functions to determine the consequences of that scenario (or simply to enumerate affected people and assets).

Consequence measures can include direct damage (direct damage in dollars, clean-up costs and repair times over an expected number of events), affected number of people, indirect disruption and reduction in services, for example, that the community would face for that scenario.

85 RiskScape is being continually developed by NIWA and GNS Science. This includes the Earthquake Commission, Quotable Value, councils and Statistics New Zealand geo-referenced inventory of New Zealand's national assets, buildings, census and land-use information, as well as asset attributes that can be used to determine how vulnerable or fragile each asset is to the relevant hazard. Collating a database of linear in-ground infrastructure remains a significant challenge for local government to progress.

The vulnerability assessment outputs will include wider considerations for the risk assessment, which will enable priority areas for planning to be identified. This will be done not just where the risk is highest but where the sensitivity or coping capacity (vulnerability) to future changes is also a consideration. Areas with both high risk and vulnerability should be priority planning areas, whereas areas with both low risk and low vulnerability are unlikely to be candidates.

For situations where the consequences or impacts of climate change on elements of the coastal environment are currently largely unknown (eg, effect of SLR on the future morphology of a complex tidal inlet or sand spit system, or rising groundwater on future flooding), determining the appropriate level of risk can be informed by using the following questions (adapted from Center for Science in the Earth System (2007)) and from expert elicitation.

- How important is the potential impact in the context of other issues or impacts?
- If you know that the likelihood of the impact is increasing, how sensitive is the exposed system to the impact across several SLR scenarios and storm conditions? (See chapters 5 and 6.)
- If the projected impact exacerbates existing stressors on the system exposed, how effective are current management responses in addressing the problem?
- What is the adaptive capacity of the people, institutions (eg, plan rules, protection structures), organisations, and infrastructure and asset networks in the area affected?

These questions will enable a preliminary assessment of the risk and consequences in the area exposed for such situations – otherwise more straight forward risk assessments can be undertaken on hazard assessments based on a range of SLR scenarios or SLR increments (chapter 6).

With input on the council and community priorities and values that will have been identified at step 3 of the decision cycle, the relative priority areas can be identified for attention at step 5 using multi-criteria analysis or other prioritising methods already used by councils.

At step 4, the VAs (comprising elements of sensitivity, vulnerability and adaptive capacity of the wider social, economic and cultural setting) and risk assessments (focused on physical consequences, service performance and public safety) for a range of climate change scenarios, along with the community values information from step 3 (chapter 7), together will identify the coping and adaptive capacity of the community and councils. These assessments will provide the evidence base for the participatory stakeholder and community evaluation of options at step 6 of the decision process. Step 6 will use a range of climate and social and economic scenarios, timeframes and their economic assessment. The output of this step will be pathways that can be incorporated into the adaptation strategy at step 7.

VAs and risk assessments are, therefore, essential tools for identifying and evaluating adaptation options and pathways at step 6, alongside economic assessments and assessments of different timeframes for implementing the response or risk-reduction option. Physical or planning response options can also be tested in risk assessments, to compare and evaluate option utility in reducing risk and under what conditions (eg, RiskScape was used by NIWA to demonstrate that raising the floor levels of vulnerable houses by 0.1–0.4 metres would have substantially reduced the flooding damage in the Flockton Basin, Christchurch, in 2014) (NIWA, (n.d)). Thus, vulnerability and risk assessments can also be used as input for determining under what conditions measures might be effective before another pathway is required, and therefore used to determine measurable early signals and triggers (decision points) for

pathway transfer. This is discussed further in chapter 9, where vulnerability is also used in the DAPP process to denote the conditions under which the policies and pathways no longer meet the objectives set at step 3.

8.3 Engagement for assessing vulnerability and risk

An overlay of the hazard and sea-level rise assessment and community values at step 3 will immediately indicate the extent of the adaptation challenge and prompt the need for further engagement with the property owners affected and the wider community. In particular, debate regarding different values and interest, questioning of scientific data and method, challenges to the process, difference in risk perception, and concern about uncertain futures and change, will emerge. These matters will need to be addressed with the wider community, not just those immediately affected or representative of the different groups (see section 3.2).

A well-designed engagement process will ensure inclusiveness, appropriateness, legitimacy and legality, and thus enable the challenges to be worked through effectively. Addressing these issues early in the decision process will help as the engagement process is repeated at subsequent stages around the decision cycle, and when the decision process is triggered as something changes. This section provides information on the types of issues that can arise and suggests methods to manage them effectively, which should include resources in chapter 3 to help identify specific engagement methods.

8.3.1 Managing different values and interests

Values and interests will be contested, because of the high value placed by people on the coastal environment, the diversity of these values and the extent of public infrastructure and private property in areas affected by coastal hazards and SLR. People develop strong attachments to the places where they live – realisation of future impacts on these places may generate a sense of loss and potential feelings of grief. In particular, the loss of homes, areas of high cultural significance (eg, marae, urupā), or recreational or natural sites that have high amenity or ecological value, are likely to engender these emotions. Communities and individuals will wish to protect the things they value, in many different ways, which may be expressed by supporting a particular 'solution', questioning the science, the process or the perceived nature of the threat. Underlying each of these is a desire to protect against loss. Tables 18–21 provide guidance for managing differences of values, differences in risk perception, distrust in scientific information, and uncertainty and change.

Table 19: Common challenges and potential responses to differences or conflicts of values and interest

Common statements	Methods designed to respond should…
I won't be able to… We will lose…	• acknowledge the emotions – emotional connections to places need to be recognised, validated and conveyed to others through creation of a safe space for dialogue (see guiding principles in chapter 3 and also Rouse et al, 2016) • focus on positive ways to change or finding ways to restore, re-establish, substitute or grieve for what has been lost or could be lost • focus on empowering participants to provide and use stories of how others have adapted or acted in the face of change

Compiled from Moser, 2016; Rouse et al, 2011, 2016.

8.3.2 Addressing urgency and differences in risk perception

The sense of urgency associated with adaptation to sea-level rise can vary greatly in a community, depending on how the magnitude and immediacy of the risk are perceived. In

general, a relationship exists between perceived risk and support for action. This will be influenced, however, by the magnitude and nature of the perceived risk, as well as the proposed action (Kettle and Dow, 2016). For example, beachfront property owners experience a high and immediate sense of risk and can demonstrate a strong desire to protect their property through the promotion of visible and familiar solutions, for example, engineered solutions such as seawalls (Blackett et al, 2010a). Conversely, someone living in the hills overlooking the beach may experience far less urgency and express a greater degree of ambivalence around if, how and when to act. Furthermore, perceived risk will likely be very different from risk as described in statistical or engineering terms, because perceived risk is a product of personal attitudes, beliefs, values and vulnerability (Kettle and Dow, 2016). Perceived risk should not be overlooked – it needs to be highlighted and discussed because it will drive behaviour.

Table 20: Common statements and characteristics of methods to respond to issues of urgency and differences in risk perception

Common statements	Methods designed to respond should…
There are more urgent things to focus on We can cope – we will be fine	• demonstrate measured changes (ie, sea-level rise data and changes in hazard frequency) to show that climate change is happening here and now • use methods to engage people in the measurement or documenting of change, so they can understand the nature and timing of the issues
My house is falling into the sea – we need a seawall now	• work with affected parties to understand perceived risk and reconcile it with risk from a technical perspective • apply methods for visualising the long term

Compiled from Blackett et al, 2010a; Moser, 2016; Rouse et al, 2011.

8.3.3 Dealing with distrust or questioning of scientific data and method

Climate change science can be questioned in many ways in the context of coastal management; for example, the validity of the science of climate change, the rate of change in the future (modelled projections), uncertainties and the role of science in decision-making.

Table 21: Common statements and characteristics of methods to respond to distrust or questioning of scientific data and method

Common statements	Methods designed to respond should…
The science is still uncertain – there is no proof	• justify action because of uncertainty • emphasise the high level of consensus between scientists • demonstrate measured change in sea-level rise • engage people in the measurement of change and understanding of traditional knowledge • ensure the science used in the engagement is in line with information in this guidance (or other new climate-related information or research that has been peer reviewed)
This information disproves climate change	• emphasise the whole of the problem, focusing on the whole system • build trust and undertake joint exploration of the data or results
Climate change is a natural phenomenon	• indicate that change is ongoing, so adaptation is still necessary
This is too complex and confusing	• use simple and clear language during communication • actively demystify the science through simple framing of the problem

Compiled from Moser, 2016.

8.3.4 Facing up to uncertain futures and social change

Many climate change related uncertainties in a coastal setting (eg, rate of SLR, magnitude of impacts) and non-climate-related uncertainties (population change, policy change) will need to be addressed in any engagement process. Uncertainties are often expressed as a probability statement where impacts are known, or a range, or through the use of scenarios where there are unknowns. How these are perceived varies from person to person, even when the same information is presented (Kettle and Dow, 2016), and this will also affect behaviour. This presents two challenges: how uncertainty is presented and how it is addressed.

Table 22: Common statements and characteristics of methods to respond to uncertain futures and social change

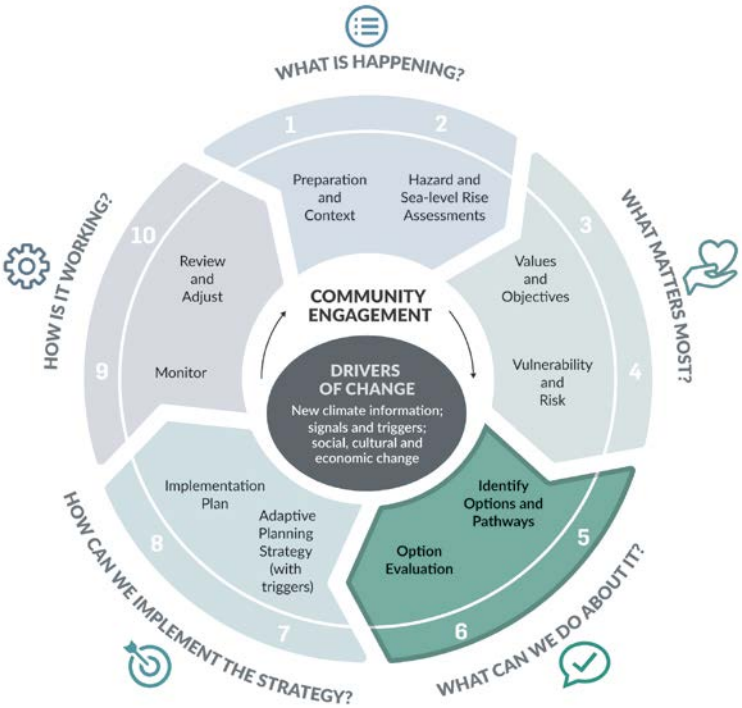
Common statements	Methods designed to respond should…
There is too much uncertainty to do anything We need to reduce uncertainty before we do anything	• employ an approach that is robust in many different possible futures, eg, use scenarios, adaptive pathways approaches • use analogous decisions in everyday life where there is uncertainty, and discuss how these are dealt with by participants • explain why sea level is rising and how coastal hazards and hazard risk can be addressed

Section C: What can we do about it?

9 Adapting to changing coastal risks arising from climate change impacts

Chapter 9	**Chapter 9 covers:** • what we are adapting to and why • what we mean by adaptation and adaptive capacity • context for adaptation decision-making • identification of options and pathways • evaluation of options • community engagement in these steps.
Steps 5 and 6	**Key tasks** a. Gives guidance on: • options and their identification • how to build options and adaptive pathways • how they can be evaluated • engagement with communities. b. Provides advice on decision-making tools.

Figure 63: Steps 5 and 6 in the decision cycle: What can we do about it? – identify options and pathways and option evaluation



9.1 Introduction

Exacerbation of existing coastal hazards by ongoing sea-level rise (SLR) will create new wider-scale risks not previously experienced in coastal areas (see chapters 1 and 4–6). This has implications for making decisions today, especially for those activities or assets that have long lifetimes in coastal areas likely to be affected by climate change related impacts. These include:

- intensification of existing development
- location of new development
- provision of utilities and services below and above ground
- the design and location of major new infrastructure
- adaptation of existing development.

In addition, responses to the more intense impacts can affect wider community values at the coast, such as public amenity, recreation, coastal habitats and other environmental aspects. Adverse effects can thus arise from both the hazards themselves and the human responses to them. The capacity to adapt will be different for different groups in the community, according to their vulnerability.

In the face of ongoing SLR, not all coastal locations will be able to be 'protected' by hard or soft engineering approaches in the long term, due to physical, spatial, scale and affordability constraints. Box 4 sets out the situations where different natural protection options are appropriate, with the overall objective to reduce coastal hazard risk. The New Zealand Coastal Policy Statement 2010 (NZCPS 2010) (Department of Conservation, 2010) also flags the need to identify and plan for transition mechanisms and timeframes for moving towards more sustainable approaches (Policy 27, NZCPS 2010) (chapter 2).

9.1.1 What are we adapting to and why?

Chapter 6 explained the range of potential coastal hazards, along with the level of uncertainty attached to our knowledge of them. Coastal hazards include:

- hazards we know about and that can be managed using current tools
- some that will compound because of SLR and become cumulative hazards, thus increasing hazard risk (such as saltwater intrusion and rising groundwater levels causing surface ponding, combined storm tide and river flood and drainage impacts)
- unknown aspects of SLR, such as the rate of change and its magnitude arising from the uncertainties around polar ice sheet stability, and the spatial extent and scale of the impacts.

The risk associated with the hazards is rising in coastal areas due to human, climate change and compounding impacts, such as:

- increasing exposure to coastal hazards driven by ongoing development and associated population growth and rising property and asset valuations
- the nature of the responses to the hazard risks
- exacerbation of existing hazard risk, largely driven by sea-level rise compounded by storm surges and king tides
- faster rates of sea-level rise, influenced increasingly by the contribution from ice sheets.

Guiding practice

- Frequency of coastal storm inundation will continue to increase. For example, flood events that currently occur rarely (eg, 1 per cent annual exceedance probability level) will become an annual occurrence with only a modest sea-level rise (SLR) of about 0.3 metres. This SLR is expected to occur by 2065 (Parliamentary Commissioner for the Environment, 2015). Uncertainty in the rate of change in sea level will increase through the rest of this century and beyond, however, and increasingly from polar ice sheet instabilities.
- For near-term decisions that intensify development in already exposed areas, and decisions on assets that have long life times, the ability to make adjustments over time will need to be built in now.
- New (greenfield) development in areas exposed to coastal hazards exacerbated by SLR should be avoided (New Zealand Coastal Policy Statement 2010, Department of Conservation, 2010).
- Near-term SLR will affect underground services and surface drainage networks and their performance well before higher SLR projections are reached.

Adaptation, therefore, is taking place in a dynamic system, a changing state, escalating risk, and a range of coastal futures could emerge (depending on how global emissions track in the coming decades). However the future may unfold, there inevitably will be SLR caused by emissions to date (see section 5.4). This situation has widespread implications, with sea-level rise leading to cumulative and compounding effects at district, regional and national scales. This means current decisions need to be routinely examined to determine:

- whether they will lock in new or increasingly unaffordable investment at exposed locations
- whether at some stage they will increase hazard risk (in situ or elsewhere along the coast and have environmental impacts)
- how they will affect wider community values and vulnerabilities
- the risk of acting or not acting if there is uncertain or insufficient information about the provision being considered (Resource Management Act 1991 (RMA) section 32(2)(c)) and the costs and benefits of the decisions being considered
- how they can be made flexible using adaptive measures, to enable feasible and affordable course correction over time.

9.1.2 What is adaptation?

"Adaptation is considered a response strategy to anticipate and cope with impacts that cannot be (or are not) avoided under different scenarios of climate change" (Denton et al, 2014, p 1104).

"Adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2014b, p 5).

Some types of change can be adapted to with relatively small changes to the way we currently manage the coastal environment using incremental adaptation approaches.[86] Other types of change may require completely new ways of doing things and involve large societal adjustments that are transformational in character.[87] Different types of adaptation exist (Glavovic and Smith, 2014) that are not mutually exclusive and may work together:

- **anticipatory or reactive adaptation** (ie, indirect and not necessarily conscious response to observed climate changes and/or their effects)
- **private** (initiated by individuals) and **public** adaptation (initiated by governments alone or in partnership with private interests for a preferred public outcome)
- **autonomous** (spontaneous adjustments) and **planned** (conscious and deliberate) adaptation
- some responses can be **maladaptive** (increase exposure and vulnerability, eg, seawalls and stopbanks for ongoing SLR and increased frequency of storm and flood inundation, often with distributional impacts and may have negative environmental effects).

Adaptation options at the coast can be described under the following groupings:

- **accommodate** (adjusting existing assets by using measures that anticipate hazard risk, such as raising floor levels, providing alternative inundation pathways, requiring relocatable houses)
- **protect** (holding the line using natural buffers like dunes or hard structures like seawalls)
- **retreat** (moving existing people and assets away from the coast in a managed way over time, or as a consequence of erosion and inundation damage after climate-related events)
- **avoidance strategies** (that stop putting people and assets in harm's way, primarily using land-use planning measures).

In practice, a combination or sequence of these types of measures will be needed as communities transition from increasingly affected coastal areas as the sea level rises (retreat is inevitable in some areas).

What is adaptive capacity?

The presence of adaptive capacity has been shown to be a necessary condition for the design and implementation of effective adaptation strategies (Brooks and Adger, 2004).

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86 The use of the concept of adaptation in coastal hazard situations differs from New Zealand case law relating to adaptive management developed around aquaculture and beach and river gravel extraction. In the aquaculture and gravel management context, monitoring and management is built into decisions in a way that ensures the activity is managed in a way and at a rate that enables a return to a sustainable state (ie, the activity must cease or reduce in intensity and not recommence (if it is allowed to) until the environmental indicators have returned to a predetermined state). Adaptation to climate change addresses a changing state that is dynamic and cannot be predicted over the long term, and where the change is irreversible in human timeframes (from sea-level rise), so there is no reversion to an earlier state.

87 A change in the fundamental attributes of natural and human systems, IPCC (2014b).

Adaptive capacity has been defined as:

> The resources available for adaptation to climate change and variability or other related stresses, as well as the ability of a system to use these resources effectively in the pursuit of adaptation (Brooks and Adger, 2004, p 168).

The ability to adapt relies on adaptation decisions that are flexible and adaptive and can be adjusted, whatever the rate of change in climate and sea-level rise outcomes. Tools to develop flexible and adaptable decisions are described in this guidance. They can be used for the assessments in steps 2 and 4, evaluation in step 6, adaptive strategy planning in step 7 and implementation in step 8, as shown in the decision cycle (figure 63). The extent of any adaptation deficit arising from legacy effects of previous decisions, cumulative and compounding impacts over time, and the vulnerability of the community at risk, will also influence the capacity to adapt.

Adaptive capacity also enables sectors and organisations to take advantage of opportunities or benefits from climate change. This could involve, for example, redesigning the spatial configuration of coastal development or changes in land use (eg, esplanades) that meet multi-community objectives and institutional adaptation that aids decision-makers to reduce risk exposure, sensitivity and vulnerability. Adaptive capacity therefore includes the:

- ability or potential of the governance (both formal and informal governing authorities), institutions (multi-level decision-making including across boundaries, statutory rules and measures, norms and operating procedures) and organisations (across functions and disciplines supported by leadership) to avoid and reduce risk
- ability to make adjustments in:
  - behaviour (eg, engagement with the communities to work together in the face of escalating risk, managing cross-organisational interests and leadership)
  - resources (eg, decision frameworks and tools)
  - integration between council functions that affect the coast (eg, coastal hazards, integration with council long-term plans and asset management plans, planning functions, parks and recreation, emergency management and lifelines)
  - technologies (data access and management and monitoring systems).

These capacities will all be needed to enable adaptation measures and implementation pathways to be identified, assessed and evaluated, and adaptive plans developed, implemented and monitored over long timeframes.

Adaptation can ameliorate some of the impacts if they are anticipated and considered in today's decisions, especially those that have long lifetimes. In some situations, the increased risk can be accommodated, in others the current capacity to adapt will be stretched, especially where coping ranges are exceeded under current conditions (repeated coastal inundation or severe erosion). As a result, the capacity to adapt will be increasingly challenged in the future (Burton, 2009; Parry et al, 2009), especially where current capacities and coping ranges are already exceeded under current conditions (IPCC, 2014b, Assessment Box SPM.2, table 1). This 'adaptation deficit' (IPCC, 2014b) will become critical for community well-being (eg, people unable to move homes for financial or insurance reasons) as the sea rises and eventually affects the viability of some coastal communities and the effective performance or level of service of infrastructure.

Adaptation already occurs incrementally at fixed planning junctures (eg, under the RMA and the Local Government Act 2002 through long-term plans and asset management plans). This occurs as a result of changing non-climate conditions, such as the environment (water quality, consent conditions), land-use change, urbanisation, demographic changes, markets and technology (eg, use of technology in different transport modes). The aftermath of natural hazard events also can provide opportunities for adaptation, such as:

- the retreat from the Red Zone as part of the community and asset rebuild in Canterbury following the 2010/11 earthquake sequence
- integrated adaptation between the insurance industry, Waikato Regional Council and Thames Coromandel District Council arising from a weather bomb that caused flooding north of Thames in June 2002 (Ministry for the Environment, 2004; Thames Coromandel District Council, 2012) and resulted in the permanent removal of some houses, improved flood protection for remaining exposed houses and insurance being maintained
- coastal retreat at Haumoana and Clifton (Hawke's Bay), where decisions were made following repeated coastal inundation that damaged dwellings would not be rebuilt and the road to Clifton Camp was moved back.

While these examples occurred after considerable damage, either in an extreme event or progressively, there are several councils in New Zealand building adaptive capacity through:

- hazards and risk assessments
- engagement programmes
- climate change strategies
- dynamic adaptive pathways planning
- plan provisions
- building networks across and within agencies.

This guidance builds on that experience.

For impacts that can be adapted to with relatively small changes to the way the coastal environment is currently managed, incremental adaptation approaches may be appropriate, so long as they do not increase hazard risk. Over time, adjustments at the coast will require completely new ways of doing things that transform governance and institutional measures, such as new instruments to fund adaptation and new legal expressions of risk in planning instruments. The capacity to adapt thus includes the knowledge, skills, resources, governance and institutions to implement adaptation effectively.

Understanding that hazard risks are beginning to escalate in low-lying coast areas (and will soon emerge in other coastal areas), and determining how coastal hazard risk can be managed, will enable adaptation decision-making to use the most appropriate tools, processes, policies and actions (step 5 of the decision cycle) as the changes manifest over time (see box 16).

BOX 16: FOUNDATIONS FOR DECISION-MAKING

Previous assessment methods and policy advice have been framed by the assumption that better science will lead to better decisions. Extensive evidence from the decision sciences shows that, while good scientific and technical information is necessary, it is not sufficient, and decisions require context-appropriate decision-support processes and tools (*robust evidence, high agreement*).

A sufficiently rich set of available methods, tools and processes now exists to support effective climate impact, adaptation and vulnerability decisions in a wide range of contexts (*medium evidence, medium agreement*).

Risk management provides a useful framework for most climate change decision-making. Iterative risk management is most suitable in situations characterised by large uncertainties, long timeframes, the potential for learning over time and the influence of both climate as well as other socio-economic and biophysical changes (*robust evidence, high agreement*).

Complex decision-making contexts will ideally apply a broad definition of risk, address and manage relevant perceived risks, and assess the risks of a broad range of plausible future outcomes and alternative risk management actions (*robust evidence, medium agreement*).

Scenarios are a key tool for addressing uncertainty (*robust evidence*, *high agreement*). They can be divided into those that explore how futures may unfold under various drivers (problem exploration) and those that test how various interventions may play out (solution exploration).

Recognition of local and indigenous knowledge and diverse stakeholder interests, values and expectations is fundamental to building trust within decision-making processes (*robust evidence, high agreement*).

Transformational adaptation may be required if incremental adaptation proves insufficient (*medium evidence*, *high agreement*). This process may require changes in existing social structures, institutions and values, which can be facilitated by iterative risk management and triple loop learning that considers a situation and its drivers, along with the underlying frames and values that provide the situation context.

Excerpt from Intergovernmental Panel on Climate Change, Working Group II, Fifth Assessment Report (Jones et al, 2014)

9.2 Adaptation decision-making

9.2.1 Decision context

The context in which options are developed (step 5), evaluated (step 6) and decisions made about adaptation, is complex and wide. For example, the context includes the hazards and their changing character and impacts, the risks for those affected (communities and private landowner interests), the statutory frameworks in which decisions are made (statutory mandates, responsibilities, roles, liabilities and the norms of the interests and agencies), the needs of future generations, and changing non-climate parameters, including social, cultural and economic change.

Five principles inform the decision cycle (as shown in figure 63):

- building a shared understanding of processes, hazards and community resilience
- exploring the future and how communities are affected by changing hazard risk in coastal areas

- building adaptive pathways for a sustainable future
- implementing the strategy in practice over time
- monitoring the strategy using early signals and triggers (decision points) for adjusting between pathways.

Three uncertainty considerations are especially relevant for climate change adaptation decision-making (see chapter 4), which necessitate a change in the way we approach adaptation (Walker et al, 2013):

- not all uncertainties about the future can be eliminated (*epistemic uncertainty*)
- ignoring uncertainties could limit the ability to make adjustments in the future, resulting in situations that could have been avoided (*lock-in*)
- ignoring uncertainty could result in missed opportunities and lead to unsustainable plans and decisions based on them (*path dependency*).

Historical and institutional experience of climate conditions will also tend to influence the capacity to respond (Dovers and Hezri, 2010). Adaptation decisions being taken now are responding mostly to current variability in historic experience and current capacity. As the impacts become more severe and beyond historic experience, difficult adjustments will be necessary, and the ability of society to cope will be challenged at a fundamental level.

Where likelihoods cannot be assigned because of deep uncertainty around the rate and magnitude of sea-level rise beyond 2100, scenarios and expert elicitation[88] will be required to assess the range of futures that could eventuate and their consequences. This will then contribute to the response options chosen and how they are implemented.

Engagement appropriate to steps 5 and 6, based on engagement principles in chapter 3 and establishing values and objectives in chapter 7, should be embedded in the decision processes and are set out in section 9.5.

9.3 Identify options and pathways (step 5)

This section provides guidance on adaptation options, how to identify them and how to develop pathways for evaluation at step 6 (figure 63). The outcome will be a number of pathways to achieve the objectives determined using information from steps 3 and 4.

Identifying options and pathways takes place in three steps:

1. decide council and community objectives using the outputs from steps 3 and 4 of the decision cycle
2. identify the possible range of adaptation options
3. develop pathways that meet the agreed objectives.

Note that, at each of these steps, engagement with the relevant communities will take place using the suggested approaches at regional level, or specific to the location, scale and type of task or activity. For example, the broadest scale of strategic planning should be used to prioritise adaptive planning for areas of highest natural hazard exposure, whereas potential new areas of development would be addressed through RMA planning measures to avoid any new exposure to coastal hazard risk.

[88] Expert elicitation is the synthesis of opinions of 'experts' on a subject where there is uncertainty due to insufficient data or when such data is unattainable because of physical constraints or lack of resources.

9.3.1 Decide objectives

To enable options and pathways to be developed, clarity about the objectives will be required. Community values and objectives will have been identified at step 3 in the decision process (chapter 7). Councils and other relevant agencies will have wider objectives to consider at this stage (step 5). They will need to ensure the objectives for the options and pathways reflect a long-term focus (foreseeable needs of future generations) and other considerations, such as conservation objectives or the interests of vulnerable groups in society. Each of these objectives will inform the different types of options developed and how they may be integrated into pathways over time and that will be evaluated step 6. At steps 7 and 8, the objectives and pathways will be reflected in an appropriate range of plans and techniques, including some of those set out in tables 24 to 26. Some of the objectives identified at step 3 will be measurable and will inform the development of signals and triggers at step 7 for monitoring as the plan is implemented, reviewed and adjusted over time.

9.3.2 Identify options (adaptation actions)

Where existing development is occurring in areas identified as at risk of being potentially affected (Policy 24, NZCPS 2010), it is necessary to identify and examine options in detail, prioritising areas in relation to their long-term coastal hazard risk and the decisions on harm avoidance and reduction objectives (see sections 9.3.1 and 8.2).

This step includes the identification of the range of possible actions for addressing hazard exposure at step 2, and the consequences using the vulnerability and risk assessments at step 4 (figure 63). The purpose of this step is to assemble a rich set of possible actions that reflect different perspectives.

The identification of options and then pathways over time will require contributions from across the community of interests, such as the community affected by the coastal hazards, council staff and technical experts, wider community interests, and government agencies with interests in the area affected, and those that may fund adaptation. Consideration of the options should start at a regional scale to provide the framework in which options for areas at risk are prioritised for investigation and management, consistent with the objectives set at the beginning of step 5.

At the broadest level, categories of options (see section 9.1.2) for consideration for any area identified as being at risk should include:

- maintain the *status quo* (no further development or intensification)
- prepare to retreat (and the manner in which this could be planned for and achieved)
- invest in protection of area for longer (assuming retreat or enhanced or alternative protection at some future time)
- combinations and intermediate options based on the above.

The best way to minimise and reduce coastal hazard risk is to avoid areas that are, or will become, exposed to hazards as identified using the sea-level rise scenarios and hazard assessments provided at step 3, and the vulnerability and risk assessments prepared in step 4. Avoidance can relate to both new development and intensification within existing developed areas. Note that the 'do-nothing' option should also be identified so that it can be evaluated at step 6 for the comparison directed in Policy 27(1)(b) of the NZCPS 2010. More specific measures that can be evaluated within an options framework could include:

- soft measures, such as dune restoration, wetland enhancement or creation, and beach nourishment and areas for biodiversity change to occur (eg, migration of species)

- land-use change, including transfer of development potential and land acquisition that enables reassignment of land uses through zoning, for example
- planning policies and rules through the RMA at regional and district level, based on aspects such as types and densities of land uses, building restrictions and coastal setbacks
- staged retreat, which could initially include moving buildings back on the property, an alternative lot to relocate to when a trigger is reached (eg, Whakatāne District Plan) or rerouting a coastal road
- structural options, such as seawalls, groynes, raised roads and building platforms, and storm surge barriers.

Adequacy of infrastructure for any option over time should not be overlooked. It may require separate evaluation, but urban systems cannot function without appropriate supporting infrastructure, and delaying replacement decisions places a large burden on future generations.

In practice, a combination of options or actions will be chosen and they may be staged over time, depending on the exposure of the locality (see section 9.3.3). The main criterion for choice of options is to avoid path dependency by building in flexibility at the start. This will enable the changes in SLR, and associated impacts on coastal processes, to be managed over the life of the option (see examples in chapter 10). Other criteria that inform the choice of options will be driven by the values and objectives of the community and councils, and may include coastal amenity, ease of implementation, any multiple and co-benefits, and general compliance with the NZCPS 2010 and the RMA (as applicable). In particular, for areas that have significant existing development and are likely to be affected by coastal hazards, Policy 27 of the NZCPS 2010 sets out requirements for the development and evaluation of options and strategies for reducing coastal hazard risk.

9.3.3 Identify pathways

An adaptive pathways planning approach

An adaptive pathways planning approach is used for the identification of options and pathways that will be evaluated in step 6. They will be implemented through different strategies and plans, depending on the context, at steps 7 and 8 of the decision cycle.

The adaptive pathways planning approach asks (not necessarily as sequential steps):

- What are the first impacts that will be faced as a result of climate change (outputs from step 2)?
- Under what conditions will current strategies be ineffective (outputs from steps 2–4)?
- What are the alternative options (step 5)?
- What are the different decision pathways that can be taken to achieve the same objectives (step 5)?
- How robust are the options over a range of future climate scenarios (step 6)?
- Are they flexible enough to enable a change of path in the future with minimum disruption and cost (step 6)?

An adaptive pathways approach avoids the need to have firm ‘predictions’ or to use only one preferred scenario as a basis for decision-making. It thus reflects uncertainty and the possibility of surprises in future climate change outcomes (Kwadijk et al, 2010), when planning for risk reduction over time as coastal hazard risk continues to rise (figure 65). It can also enable active community and stakeholder engagement and community capacity building.

Adaptive pathways planning is a risk-based approach that, internationally, has gained traction. It has been used in the Netherlands (Haasnoot et al, 2013) for the Delta Programme (Ministry of Infrastructure and the Environment, 2014), the United Kingdom (Ranger et al, 2013), Australia (Barnett et al, 2014) and New Zealand (Lawrence and Haasnoot, 2017). The Australian adaptation decision support tool CoastAdapt (NCCARF, 2016) has also included an adaptive pathways approach.

Adaptive pathways approaches were highlighted in the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) (Denton et al, 2014) as an iterative process that enables management of change and adaptation to climate change impacts that cannot be avoided (box 17).

BOX 17: CLIMATE-RESILIENT PATHWAYS: ADAPTATION, MITIGATION AND SUSTAINABLE DEVELOPMENT

Climate change calls for new approaches to sustainable development that take into account complex interactions between climate and social and ecological systems. Climate-resilient pathways are development trajectories that combine adaptation and mitigation to realise the goal of sustainable development. They can be seen as iterative, continually evolving processes for managing change in complex systems. Adaptation is considered a response strategy to anticipate and cope with impacts that cannot be (or are not) avoided under different scenarios of climate change.

Climate-resilient pathways include strategies, choices and actions that reduce climate change and its impacts. They also include actions to ensure effective risk management and adaptation can be implemented and sustained (*high confidence*; *medium evidence*, *high agreement*).

Prospects for climate-resilient pathways are related fundamentally to what the world accomplishes with climate change mitigation, but both mitigation and adaptation are essential for climate change risk management at all scales (*high confidence*; *medium evidence*, *high agreement*).

To promote sustainable development in the context of climate change, climate-resilient pathways may involve significant transformations (*high confidence*; *medium evidence*, *high agreement*).

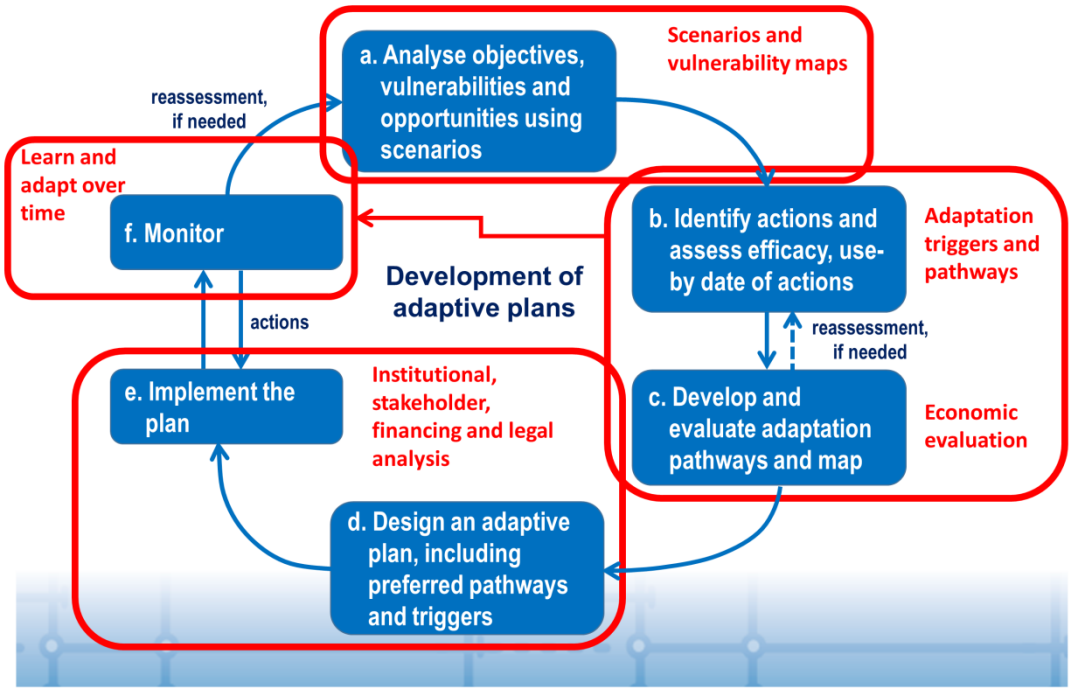
Strategies and actions can be pursued now that will move toward climate-resilient pathways, while at the same time helping to improve livelihoods, social and economic well-being, and responsible environmental management (*high confidence*; *medium evidence*, *high agreement*).

Delayed action in the present may reduce options for climate-resilient pathways in the future (*high confidence*; *medium evidence*, *high agreement*).

Source: Executive Summary, Chapter 20 Climate-resilient pathways: adaptation, mitigation, and sustainable development, Intergovernmental Panel on Climate Change Fifth Assessment Report (Denton et al, 2014)

The adaptive pathways planning approach has evolved into the dynamic adaptive policy pathways (DAPP) approach (Haasnoot et al, 2013; Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2014). This is shown in figure 64, and conceptualises a series of actions over time (pathways) to achieve a set of predefined objectives under uncertain and changing conditions. The DAPP approach can track both policy implementation and any changing conditions, and different pathways can result in achieving the same objectives. The DAPP approach is built on the notion that decisions are made over time in dynamic interaction with the system itself and cannot be considered independently or predetermined. The 10-step decision cycle (figure 1) used in this guidance incorporates these components.

Figure 64: Dynamic adaptive policy pathways approach

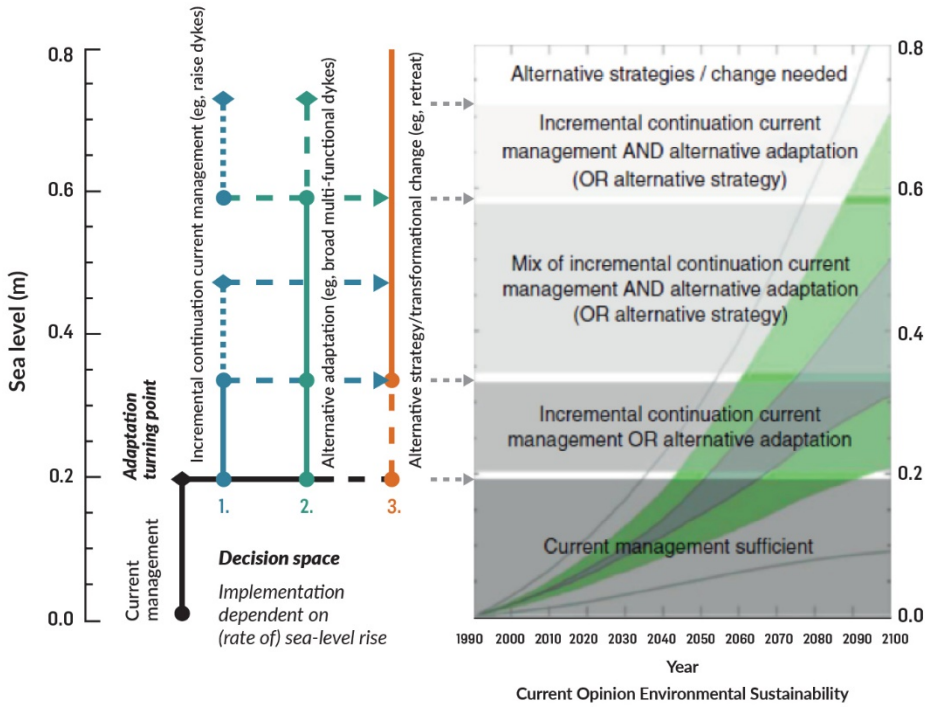


Source: Adapted from Haasnoot et al (2013)

Policies and decisions have a design life and will eventually start to fail as the operating conditions change (Kwadijk et al, 2010), for example, as the sea level rises and frequency of events exceeds an agreed threshold. Once actions fail, additional or different actions are needed to achieve objectives, and an alternative pathway emerges (figure 65 shows shifts in pathways in relation to SLR triggers).

By exploring different pathways using transient scenarios, an adaptive plan can be designed that includes a mix of short-term actions and long-term options. The plan is monitored for early signals and a trigger leading up to a decision point that indicates when the next step of a pathway should be implemented, or whether reassessment of the objectives or the plan itself is needed, necessitating a return to the start of the decision process (see figure 1, 10-step decision cycle, and also a feature within the DAPP process in figure 64).

Figure 65: Adaptation route map showing how different adaptation options combine into adaptation pathways: current management (black): raise dykes or stopbanks (blue), broaden dykes (green) and retreat (red)



Each option is effective for a distinctive range of sea-level rise, after which a shift to another option is needed (indicated by arrows). Pathways are implemented depending on improved projections or observed climate change. Source: Werners et al (2013) – with permission

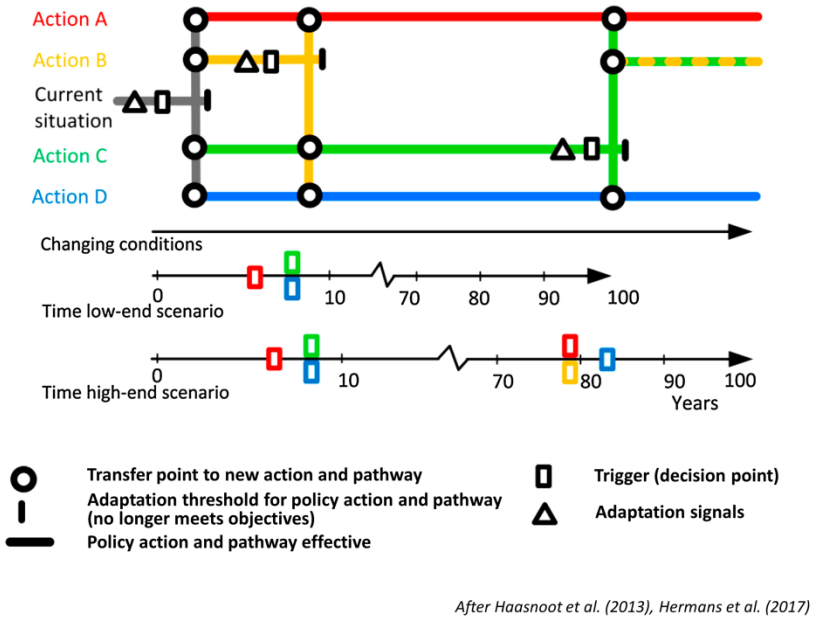
Climate scenarios allow options to be 'stress tested' for their ability to meet objectives, providing a pathway from known territory into uncertain futures, for example, using the H^+ SLR scenario (chapter 5) in the hazard and risk assessments to evaluate whether the response options can still meet the objectives, and to identify trigger points in the future for transferring to another pathway.

Once options have been identified, they should be described in detail and then 'stress tested' against the objectives decided at step 3 and criteria that address uncertainty and robustness over time. Criteria should include:

- flexibility (able to be adjusted with minimum transfer cost to other options, or the same option adjusted)
- avoidance of lock-in and path dependency
- meeting stated objectives over at least 100 years
- performance of the options and pathways over a range of climate change and non-climate change scenarios of the future.

Figure 66 shows an adaptation pathways map. Similar to a Metro map, the adaptation pathways map presents alternative routes for getting to the same point (objective) in the future. All routes presented satisfy a pre-specified minimum performance level, such as a threshold that determines whether results are acceptable or not. They can, therefore, be considered as 'different ways leading to Rome' (similar to different routes to a specified destination on the Metro). Also, the moment of an adaptation threshold (terminal station) and the available actions after this point are shown (via transfer stations), and the point at which a decision is required (trigger or decision point) (Haasnoot et al, 2013). See appendix G for further information.

Figure 66: An adaptation pathways map



Graphics: Marjolijn Haasnoot, Deltares and TU Delft the Netherlands

9.4 Options and pathways evaluation (step 6)

At step 6 in the decision cycle (figure 63) the options and pathways are evaluated using a number of tools, depending on the objectives and options being considered and the level of the evaluation effort (see figure 13). Of the different tools available, some deal better with uncertainty and dynamic changes over time than others (see figure 67 and table 23). Some will be necessary if the adaptation plan is implemented through the RMA (including the NZCPS 2010), Local Government Act 2002 and Soil Conservation and Rivers Control Act 1941, mediated through a multi-partnership agreement approach or through non-statutory plans (figure 67).

This section sets out information on a range of tools that can be used to address uncertainty in decision-making, and that can address sea-level rise effects. They are all based on robustness, meaning the ability to perform over a range of climate futures. They use iterative and adaptive planning methods to test different strategies across a number of scenarios to reflect the uncertainty, to either improve strategies or build an adaptive plan that is able be adjusted in the future without creating path dependency and lock in of land uses in areas exposed and sensitive to coastal hazard risk.

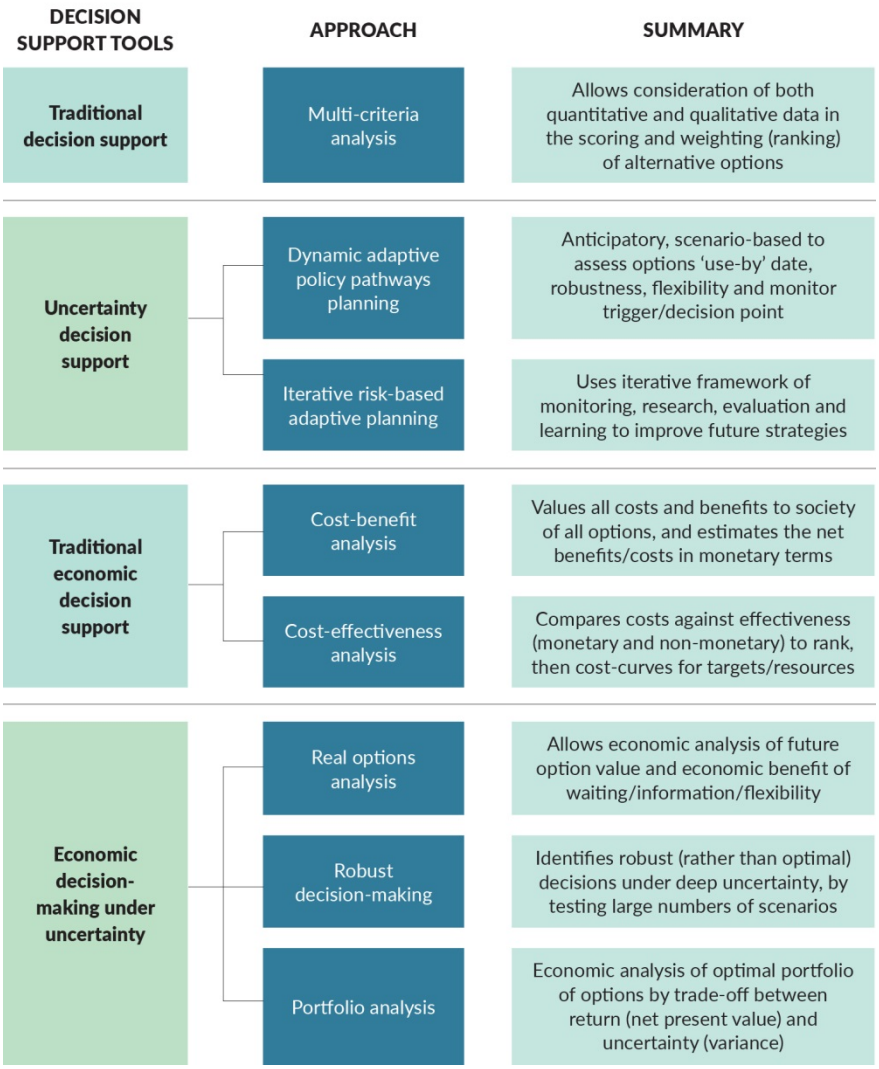
To gauge the performance of options and combinations of options over at least 100 years to meet the identified objectives, they should be evaluated against a range of climate change scenarios (eg, sea-level rise, section 5.7; and waves and storm surge, section 5.9) for their:

- flexibility
- path dependency
- feasibility of implementation
- ability to meet community values and provide co-benefits
- sensitivity to compounding impacts
- sensitivity to discount rate
- sensitivity to review date

- costs and losses, to assess value for money
- timing of options
- environmental effects.

Tools that can be used for evaluating options are shown in figure 67. These can be used in combination, but some will be better for evaluating pathways that will need to change over time, for example, adaptive approaches (DAPP). For valuing options, multi-criteria analysis (MCA) (commonly used in New Zealand) is a more subjective approach and requires clear criteria and systematic application to avoid bias. Errors always occur, however, in the estimates of costs and losses using other approaches, such as real options analysis (ROA), used for valuing pathways such as in the Thames River for future sea-level rise (Ranger et al, 2013). However, both methods used together for valuing options and pathways can be complementary. They can be used for checking the robustness of MCA results and comparing the ROA incremental investment cost differences between the various flexible pathways, using the MCA results to enable meaningful comparisons of value for money. Such an application was used by Greater Wellington Regional Council for the Hutt River example shown in box 18 for valuing pathways (Greater Wellington Regional Council, 2015a).

Figure 67: Range of decision support tools



Tools in light-blue colour relate to more traditional approaches and those coloured green to newer approaches to decision-making under uncertainty. Note: NPV = net present value. Source: Adapted from Watkiss et al (2015)

Table 23 shows in what circumstances different tools are applicable, their usefulness, limitations and potential uses. The tools are not options; rather they are used for different types of evaluation and in different circumstances. They can be used in combination where appropriate.

Table 23: Applicability of different decision support tools

Tool	Applicability	Usefulness & limitations in climate adaptation context	Potential uses of approach
Cost–benefit analysis (CBA)	Short-term assessment, particularly for market sectors.	Most useful when climate risk probabilities known. Climate sensitivity small compared with total costs and benefits. Good data is needed for major cost–benefit components.	Low- and no-regret option appraisal (short term). As a decision support tool in iterative risk management for relative costs and benefits between options.
Cost-effectiveness analysis (CEA)	Short-term assessment for market and government sectors. Particularly relevant where clear headline indicator and dominant impact. Less applicable for cross-sector and complex risks.	Most useful when: as for CBA, but for non-monetary metrics (eg, ecosystems, health). Agreement on sectoral social objective (eg, acceptable risks of flooding).	Low- and no-regret option appraisal (short term). As a decision support tool in iterative risk management.
Multi-criteria analysis (MCA)	Integrates both quantitative and qualitative (intangibles) information when comparing options.	Highly adaptable, but requires careful application and documentation. Needs to be tailored to circumstances, but can build in considerations, such as ability to adapt, interdependencies, future-proofing and cost.	Simple and effective general framework for comparing options in the short, medium and long term, and can contribute to policy development. Relies on informed judgement. Identifies fatal flaws and degrees of difficulty. Different weighting systems can be applied to identify sensitivity to different criteria.
Iterative risk assessment (IRA)	Framework for assessment and planning for complex risks or long timeframes. Applicable at project and strategy level.	Most useful when: clear risk thresholds; mix of quantitative and qualitative information. For non-monetary areas and changing risks, eg, climate change adaptation, ecosystems, health.	Flexible, very relevant for medium to long term where potential exists to learn and react. Applicable as a general framework for adaptation policy development.
Dynamic adaptive policy pathways (DAPP) planning	For assessing and planning for risks over long timeframes where change is central. Applicable at project or strategy level.	Most useful when: high uncertainty in the future and when near-term decisions have potential to create path dependency and lock in. Can be used alongside CBA, cost effectiveness and ROA for economic valuation and sensitivity assessments.	As an analytical planning framework. Flexibility analysis of options for climate change adaptation using scenarios and for monitoring triggers for anticipatory planning.

Tool	Applicability	Usefulness & limitations in climate adaptation context	Potential uses of approach
Real options analysis (ROA)	Project-based analysis. Large irreversible capital investment, particularly where existing adaptation deficit. Comparing flexible versus non-flexible options.	Most useful when: large irreversible capital decisions; climate risk probabilities known or good information. Good quality data exists for major cost benefit components.	Economic analysis of major investment decisions, notably major flood defences, water storage. Potential for justifying flexibility within major projects.
Robust decision making (RDM)	Project and strategy analysis. Conditions of high uncertainty. Near-term investment with long life times (eg, infrastructure).	Most useful when: high uncertainty in rate and magnitude of climate change signal. Mix of quantitative and qualitative information. Non-monetary areas (eg, ecosystems, health).	Identifying low- and no-regret options. Testing near-term options or strategies across number of futures or projections (robustness). Comparing technical and non-technical sets of options.
Portfolio analysis (PA)	Analysing combinations of options, including potential for project and strategy formulation.	Most useful when: a number of adaptation actions likely to be complementary in reducing climate risks. Climate risk possibilities known or good information.	Project-based analysis for future combinations for future scenarios. Designing portfolio mixes as part of iterative pathways.

Source: Adapted from Watkiss et al (2015)

The evaluation tools chosen in any situation need to reflect the stage in the decision process, nature and scale of the issue, the objectives to be achieved and the options identified. To ensure robustness, it will be essential to apply the evaluation tools to a range of scenarios and to identify future trigger or decision points (chapter 10).

Guiding practice

Dynamic adaptive policy pathways (DAPP) planning is particularly useful for making decisions in the coastal context, where dynamic characteristics are leading to ever-changing risk profiles and uncertainty exists around rates and magnitude of changes, especially over the long term.

DAPP focuses on making transparent what the dependencies are between actions, and whether options will result in lock in of existing risk or create future exposure to hazard risk, while keeping multiple pathway options open for the future. This helps to reduce the risk of irreversible decisions (Kwakkel et al, 2016).

Importantly, DAPP does not prescribe a single solution that is embedded at the start. Future options are left for future decisions, provided they help to achieve the stated objective. This means some certainty exists for the community about what the future possible pathways entail. Transparent trade-offs can be made where there are competing options and different values in communities that can be made explicit. Informed debate can then take place on options with an awareness of how these actions might affect future decision-making (Kwakkel et al, 2016).

DAPP[89] is an approach that can be used at the options identification and evaluation stages (steps 5 and 6), and for identifying under what conditions the options no longer meet the desired objectives. It enables many options to be assessed and pathways to be developed, either in sequences or combinations of options. This enables an adaptive strategy (step 7) to be built and each pathway to be assessed for its costs (tangible and intangible) over time, including the transfer costs of changing course when options can no longer meet the stated objectives (see appendices G and H).[90] The approach has utility in addressing the requirement for evaluation of costs and benefits under the RMA (section 32) and Policy 27 of the NZCPS 2010.

The application of dynamic adaptive pathways planning for the Hutt City Centre Upgrade Project is shown in box 18. In this example, following option identification, the options were assessed against three climate change scenarios and the effects of the options were assessed according to relative costs, whether the objective (in this case, the level of service for flood protection) would be met (target effects) and whether there were positive or negative social, transport and environmental effects. This was first carried out as a qualitative assessment using MCA (by expert elicitation) followed by an options value assessment using ROA to test the sensitivity of the options to climate scenario, discount rate, decision review date, costs and losses (Greater Wellington Regional Council, 2015a).

BOX 18: APPLICATION OF DYNAMIC ADAPTIVE PATHWAYS PLANNING: GREATER WELLINGTON REGIONAL COUNCIL

Implementing climate-resilient decisions under conditions of uncertainty and change is a challenge for those responsible for reducing flood and coastal inundation risk. The dynamic adaptive pathways planning (DAPP) approach has been designed for this type of problem and applied in New Zealand for flood risk management in the Hutt River catchment.

Four phases over four years enabled a transition to adaptive pathways planning, facilitated by a boundary agent using a simulation game and national and international reports and events:

1. creating interest using reframing of the risk as a changing one with future consequences
2. increasing awareness, using Intergovernmental Panel on Climate Change findings
3. experimenting using a serious simulation game (appendix H) for decision-making under uncertainty
4. uptake of the DAPP approach by the Greater Wellington Regional Council.

The stages of the DAPP application included:

- addressing the objective for the Hutt River Flood Management Plan to provide for the 440-year flood standard, considering potential impacts on the Hutt River flood frequency over at least 100 years, using a range of climate scenarios. Upgrading the plan to 2800 cumecs met the standard

89 For general applicability in this guidance, DAPP refers to dynamic adaptive pathways planning (rather than the term dynamic adaptive policy pathways used specifically by Haasnoot et al, 2013).

90 A pathways generator has been designed and is available for use in New Zealand, having been tested under New Zealand decision settings during 2015/16. It can be used to help explore policy pathways in an interactive way across a range of scenarios of the future, considering a range of possible pathways together with stakeholders. www.deltares.nl/en/software/sustainable-delta-game/ (contact Dr J Lawrence at the New Zealand Climate Change Research Institute (Victoria University of Wellington) for access).

BOX 18: APPLICATION OF DYNAMIC ADAPTIVE PATHWAYS PLANNING: GREATER WELLINGTON REGIONAL COUNCIL

- identifying a range of protection and planning options to achieve the objective
- assessing the options against three climate change scenarios
- assessing the options according to relative costs and whether the objective would be met (target effects), in this case the level of service for flood protection, and whether there were social, transport and environmental effects that were positive or negative
- carrying this out as a qualitative assessment (multi-criteria analysis) using expert elicitation
- performing an options value assessment using real options analysis, to test the sensitivity of the options to climate scenario, discount rate, decision review date, costs and losses
- drawing the results of these assessments as a series of pathways showing at what point the objectives were no longer reached
- presenting the resulting adaptation pathways map (figure A), which shows options, scenarios, decision moments, relative costs of options and potential side effects requiring consideration. Relative impacts are indicated with – and ++; – is negative impact and + positive impact.

Pathways 2C and 4 were consulted on, and pathway 2C was preferred by the community and adopted by Greater Wellington Regional Council.

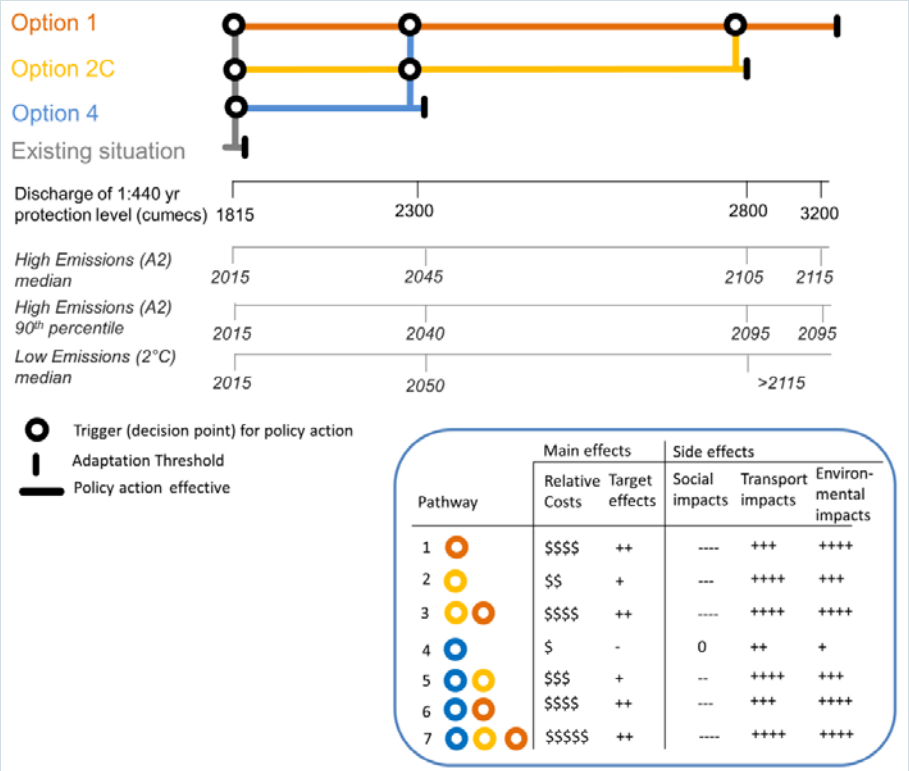
Source: Adapted from Greater Wellington Regional Council (2015a, 2015b)

Each option consists of a portfolio of measures, and for each portfolio the 'adaptation threshold' conditions were assessed in terms of the flood discharge it can accommodate. Three options were taken forward for further evaluation using the DAPP. Figure A shows a pathways map like the Metro map shown in figure 66.

All routes presented satisfy the minimum performance level in terms of the 1:440-year protection level. For example, it is possible to first implement a 70-metre river channel with property purchases after 20 years (option 4). This option reaches an adaptation threshold if the 1:440-year discharge is 2300 cubic metres per second. Depending on the scenario, this can occur in 2040–50. After this adaptation threshold, this river channel can be extended to 90 metres, possibly with a 25 metre berm (option 2C; pathway 5 in the scorecard), or with a 50 metre berm (option 1, pathway 6 in the scorecard). The scorecard shows that pathways 1, 3, 6 and 7 exhibit the best target effect. Option 4 starts to perform unacceptably (not reaching the 1:440-year objective) after 40–50 years and so requires a staged decision to move to option 2C. Option 2C by itself reaches the target by 2095–2105, and only option 1 will enable the target to be met going beyond 100 years. A description of the options is shown in table A below.

BOX 18: APPLICATION OF DYNAMIC ADAPTIVE PATHWAYS PLANNING: GREATER WELLINGTON REGIONAL COUNCIL

Figure A: Hutt River City Centre Upgrade Project



Adaptation pathways map showing options, scenarios, decision points, relative costs of options and potential side effects requiring consideration. Relative impacts are indicated with – and ++; – is negative impact and + is positive impact. All pathways except pathway 5 have negative social impacts, because land has to be purchased.

Source: Generated by the Pathways Generator,[91] based on (Greater Wellington Regional Council, 2015a)

Table A: Hutt River City Centre Upgrade Project options and costs

Option	Description	Cost	Total discounted costs + loss figures
Option 1	A 90 metre river channel and 50 metre berm; right and left stopbanks meet the standard over 100 years in all scenarios	$267 million	$270
Option 2C	A 90 metre river channel 25 metre berm; properties to be purchased	$143 million	$154
Option 4	A 70 metre river channel; 30 years of flood protection; lower level of protection (2300 cumecs); properties purchased after 20 years	$114 million until 2035	$202
Staged Option 4 to 2C		Additional $68 million = $182 million	$185

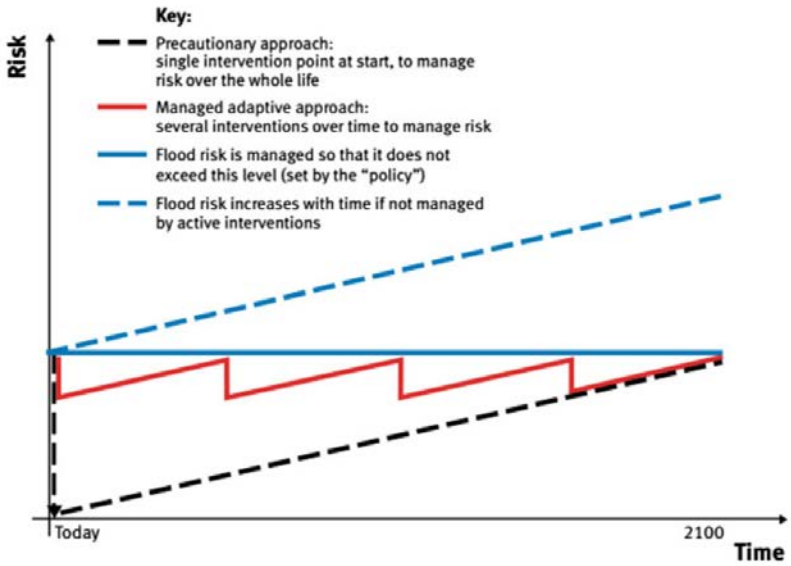
Source: Based on Greater Wellington Regional Council (2015a)

91 See http://pathways.deltares.nl/.

By developing and mapping these pathways and analysing the elements of each option, the assumptions of the analysis can be made transparent and fed into the development of an adaptive plan for implementation at step 7. The approach anticipates a range of future circumstances. It enables measured and considered decisions to be made and embedded in policy and plans (of various types), rather than reacting to events as they happen. An adaptive pathways planning approach enables decisions to be taken in stages over time. It does this by first setting objectives, then deciding adaptation thresholds based on predetermined conditions that are acceptable or tolerable to those affected by coastal hazards, and identifying triggers (step 7, chapter 10) with earlier signals that enable enough lead time to implement the response options by the time the adaptation threshold is reached, and thus retain flexibility for the future.

Another example of pathways planning was that used for the Thames Estuary plan. This is shown conceptually in figure 68 as an evolution of risk over time that led to the adoption of decision triggers linked to sea-level rise and the performance of the Thames Barrier over time.

Figure 68: Evolution of risk in an iterative risk management approach



Source: United Kingdom Environment Agency 2012 TE 2100 Plan for the Thames Estuary, in Ranger et al (2013), graphic reproduced with permission

9.5 Community engagement

Engagement appropriate to steps 5 and 6 of the decision cycle, based on the engagement principles in chapter 3 and community and stakeholder values and objectives in chapter 7, should be embedded in the decision processes and are set out here.

Chapter 3 sets out the community engagement principles that need to be embedded in adaptation planning for existing development and for adaptation of council infrastructure, roads and services. Chapter 7 sets out who might be included in the engagement process and how it might be conducted to help in understanding community values at different scales. Aggregating community and council objectives at the regional and/or district scales will help to set local objectives guiding the coastal adaptation planning process.

Inclusion of the community in the identification of options and pathways is essential, particularly for existing settlements or suburbs that are currently, or soon to be, exposed to coastal climate change effects. It will provide deeper understanding for the community and decision-makers about what options and pathways might meet the community and council objectives (step 3, chapter 7). It will also highlight what is able to be implemented,

considering feasibility, ability to meet objectives (for how long; under what conditions they fail to do so) and funding mechanisms.

Inevitably, community engagement will provide new ideas not necessarily identified by technical experts or the council. The inclusion of the community enables transparency to be maintained about the process, how options evolve, what was and was not included and why. Brainstorming alternative options, including novel ones, will avoid narrowing down the options too early. A combination or sequence of options for implementation over time is likely to be chosen and presented as alternative pathways. These can be evaluated in step 6 of the decision cycle (figure 63) against the hazard, vulnerability and risk assessments for different scenarios provided in chapters 6 and 8. This allows the options to be evaluated for their sensitivity to a range of climate conditions, thus taking account of uncertainties in longer term SLR projections.

Inclusion of community stakeholders can be achieved in various ways (table 24). This should be set up to consider, for example, what options can protect the things of value, what options would minimise conflict, and how to ensure elements that are highly valued are considered.

Table 24: Approaches for including community interests in options and pathways identification

Methods	Description	Examples
Key informant interviews	Interviews with key groups within the community (iwi and stakeholders) to obtain insights and thoughts. **Advantages**: Obtains a good level of detailed information on relevant topics. Obtains views of those who are not comfortable contributing in other forums. **Disadvantages**: May not access key individuals who represent different groups and so may miss a section of the community. No opportunity for community to listen to or learn from other participants or groups.	Lakes Entrance, Victoria, Australia (Barnett et al, 2014)
Workshops, hui (whole of community)	Public meetings, hui or other events (eg, open days, field days) and workshops can be organised to brainstorm options. **Advantages**: Suited to the local scale where local and indigenous knowledge is important and there is a high degree of familiarity with the local environment. Can be repeated several times with different groups across the community. **Disadvantages**: May miss sections of the community that cannot attend. No opportunity for wider interests to hear dialogue.	King et al, 2011, 2012, 2013 Rouse et al, 2011, 2013; Rouse and Blackett, 2011
Workshops with selected representatives	Brainstorm with key groups and sectors to collate thoughts and ideas, or use the New Zealand (serious) Coastal Game (appendix H) to stimulate decision-making under conditions of uncertainty and understanding of adaptive planning. **Advantages**: Suited to the local scale (although applicable at a bigger scale, depending on participants), listening and learning can be built in to the process. **Disadvantages**: Representatives will need to be well connected with the groups they represent to enable grounded input.	*Clifton to Tangoio Coastal Hazards Strategy 2120 – Strategy Development* (Coastal Hazard Committee, 2016) Hutt City Centre Upgrade Project (Greater Wellington Regional Council, 2015a, 2015b)

Within each of these broad approaches, creative methods can be employed to encourage thinking and brainstorming to stimulate decision-making under uncertainty. Chapter 3 provides links to resources that will help identify appropriate or relevant methods. Other critical resources can be found in the negotiation, conflict resolution and mediation literature.

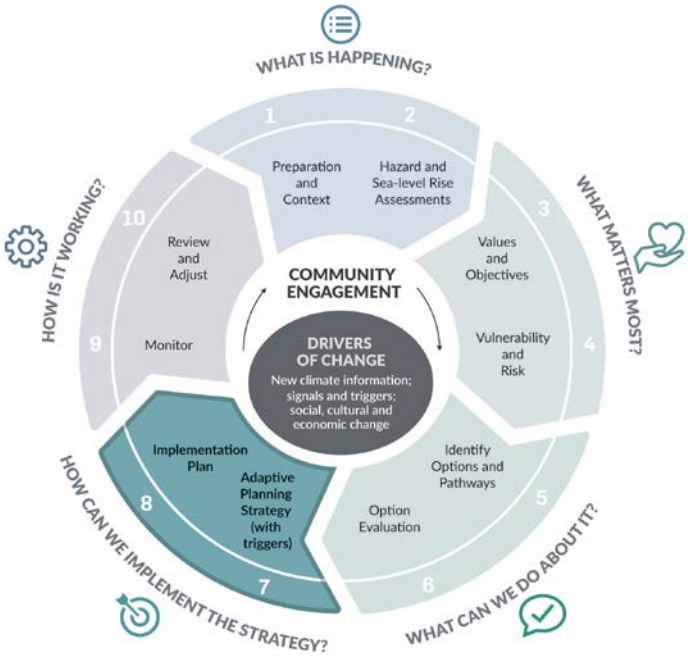
Appendix I has adaptation case studies that provide examples on various approaches that have been applied including community engagement.

Section D: How can we implement the strategy?

10 Adaptive planning strategy and implementation

Chapter 10	**Chapter 10 covers:** • developing an adaptive planning strategy • how to develop signals and triggers (decision points) • guidance on implementing an adaption framework and response measures • scope of planning frameworks • range of response options and measures (in tables) • community engagement in these steps.
Steps 7 and 8	**Key tasks** a. Develop and agree on signals and triggers (decision points) for pathways planning. b. Explore a range of planning and adaptation response options (see tables). c. Work through choice of response methods and techniques in collaboration with community, iwi/hapū and stakeholders. d. Develop an implementation strategy including a long-term financing plan.

Figure 69: Steps 7 and 8 in the decision cycle: How can we implement the strategy? – adaptive planning strategy and implementation plan



10.1 Adaptive planning strategy

This chapter provides guidance on developing an adaptive planning strategy, developing signals and triggers (decision points), and how to implement the plan over time through different planning frameworks. It also covers the current suite of statutory planning techniques that can be used.

Once the options have been identified and prioritised, and adaptive pathways developed and evaluated, the adaptive strategy can be developed at step 7 (figure 69). The development of the adaptive planning strategy has two steps:

1 developing signals and triggers (decision points) at step 7 for monitoring the plan later at step 9, to allow review and adjustment at step 10 (chapter 11)

2 identifying which frameworks and measures will be used to implement the plan.

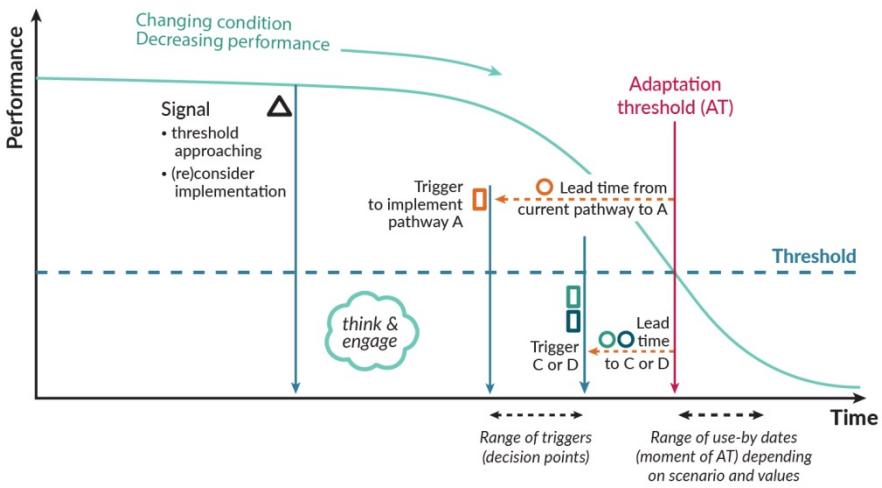
10.1.1 Developing early signals and triggers (decision points) before reaching the adaptation threshold

To monitor the strategy as conditions change over time, it is necessary to have a way of measuring when an option or pathway cannot meet its objectives and thus needs to be adjusted. This means an advance signal or warning system is required. Traditionally, warning systems occur close to an imminent threat, for example, a heavy rainfall event or a coastal storm. Such signals can be misleading, because they are often dependent on extreme events or can be 'missed' because of natural variability. They can be identified falsely as climate change signals, because they attract decision-makers' attention. Early signals are necessary to allow for the lead time and adjustment to an option or pathway to be made and the trigger point for the change in course to be identified.

Signals that appear early in the 'impact chain' are preferable because they give more time for the decision to be made about whether to change the response option or pathway, and to implement any change. They are, however, less visible and can appear less policy relevant, resulting in information that is less 'convincing' to decision-makers (Kwakkel et al, 2016).

A schematic summarising and communicating signals and triggers (decision points), when a pathway or option needs to switch, is shown in figure 70. It shows an example couched in terms of decreasing service performance, which could be from increasing coastal hazard and sea-level rise impacts on a drainage or stormwater system, or an existing seawall. The performance threshold could be related to a sea-level rise or a frequency of coastal inundation or erosion. Forward planning highlights an early warning point (signal) when implementation of the current option (pathway) may need to be reconsidered in light of substantial social or economic changes, new information or projections. The schematic also shows the lead time required before a switch to the next agreed option or pathway (eg, to cover time for detailed design, consenting and implementation, which in some case may include construction).

Figure 70: Signals and triggers (decision points) relative to the adaptation threshold



Note: A, C and D refer to pathways in figure 66, with different lead times.

The use of socially defined triggers that are frequency and/or tolerance based, and designing responses that can anticipate them (see figure 71), can be useful, particularly if these have been transacted with the affected community.

Specific coastal examples could relate to infrastructure, such as increasing frequency of clearance of stormwater drainage systems, measurement of saltwater in groundwater systems, and increasing cost and complexity of maintaining pumping systems. These can be useful early signals. Whatever system is chosen, it must be relevant to the particular circumstances. The Australian example in box 19 and figure 71 shows socially defined triggers that were developed using a mix of engagement methods.

BOX 19: PATHWAYS AND TRIGGERS DEVELOPED FOR LAKES ENTRANCE, VICTORIA, AUSTRALIA

Lakes Entrance (Victoria, Australia) sits behind a barrier dune at the eastern end of a large coastal lagoon system fed by six rivers. The town is located at the one permanent opening between the Gippsland Lakes and the sea.

The town floods when there is a combination of high tides, low-pressure systems and intense rainfall. Studies of potential climate impacts on Lakes Entrance have concluded that climate change will cause:

- an increase of the 1:100-year flood level at Lakes Entrance by 2–20 centimetres in 2030, relative to baseline flood levels (set in 1952), and by 4–59 centimetres by 2070
- increased sediment transport from west to east along the coast, but not such that there is a significant risk of a permanent breach in the barrier dune until later this century.

Informed by various studies, in 2010, after a complicated planning dispute about preparing for sea-level rise, the Victorian Civil and Administrative Tribunal imposed a series of unprecedented interim controls on building developments in the town. These were unpopular with local people, caused conflict and were potentially maladaptive and unsustainable. The controls stimulated a more strategic discussion about how to better adapt to sea-level rise. A product of this was a three-year research project and the development of local adaptation pathways in partnership with the East Gippsland Shire Council and three state government organisations.

The steps in this process were:

1. Secondary data about the town was collected about the population and economy, its geomorphology and ecology, anticipated climate impacts and its history of resource management and adaptation.
2. Primary information was collected:
    a. 30 interviews with policy actors, operating at federal (five), state (13) and local (12) tiers about existing adaptation institutions
    b. 18 interviews with residents
    c. a phone survey of 199 local residents and second-home owners to ascertain their lived values. Interviews with residents sought to understand local perceptions of existing coastal flooding and environmental change
    d. researchers also participated in various local events and meetings.

BOX 19: PATHWAYS AND TRIGGERS DEVELOPED FOR LAKES ENTRANCE, VICTORIA, AUSTRALIA

3 Interviews revealed the nature of policy actors' and residents' concerns about existing sea-level rise adaptation policies, and provided perspectives on how these limitations could be addressed. The analysis revealed that both groups believed equitable adaptation must take time to lay out information, allow local ownership of the adaptation process and then allow people time to adapt.

4 The interviews and phone survey of residents revealed what people value about Lakes Entrance and what of these are most at risk of sea-level rise, and the associated adaptation actions. The analyses of these three data sets pointed to the need for an adaptation pathway for Lakes Entrance and provided the foundation for scoping what a pathway might look like.

5 In the final year of the project, the relevance and feasibility of an adaptation pathway in Lakes Entrance was empirically tested. A six-hour workshop was held with four key local decision-makers with responsibility for coastal, community and emergency planning and management. In this workshop, the concept of a pathway was explained, and the goals, triggers and actions at each step of the pathway were proposed and extensively discussed.

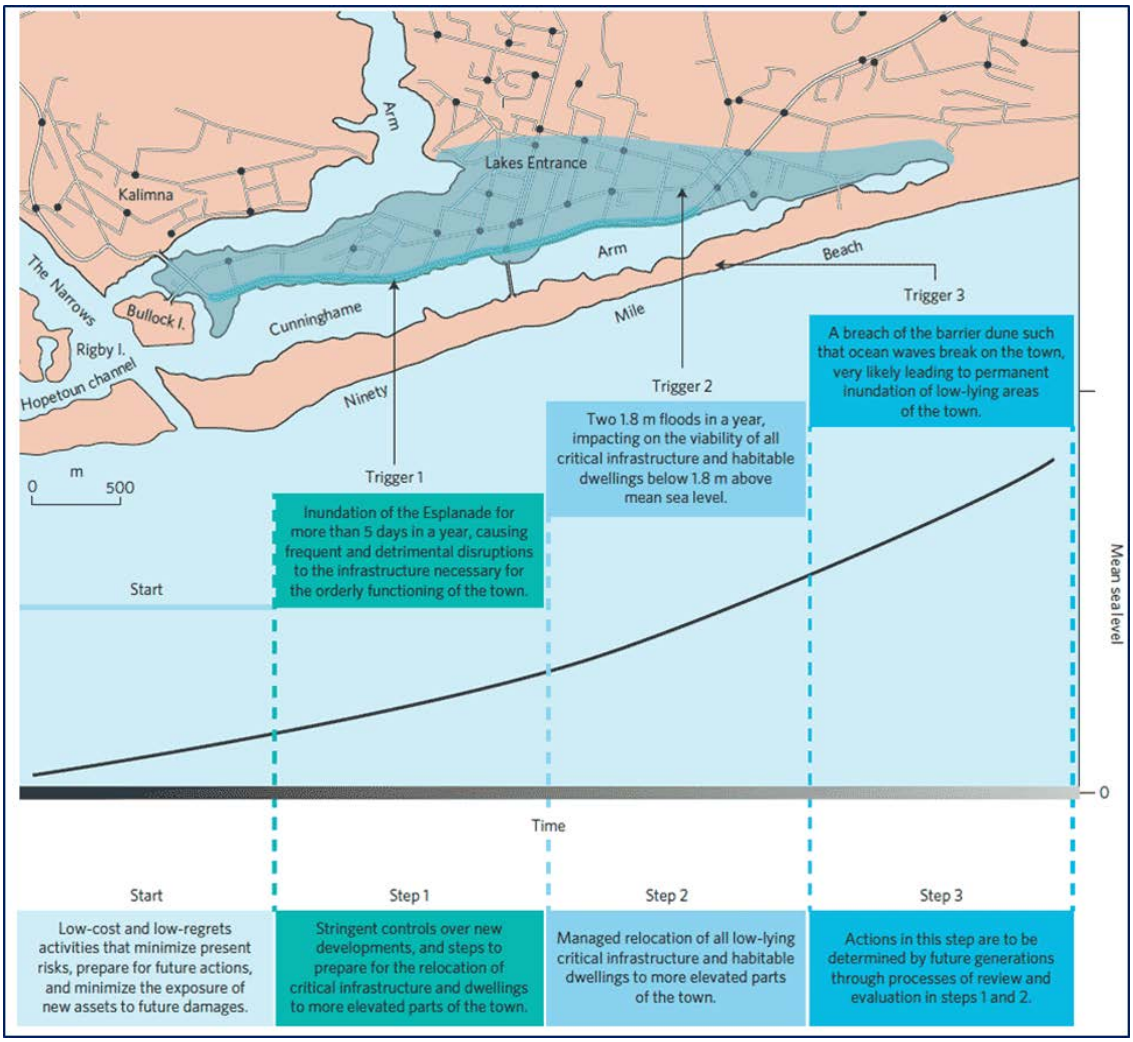
6 The workshop outcomes were then further refined with three two-hour focus groups comprising residents of Lakes Entrance. The participants broadly reflected the demographics, except that young people under 30 years old and indigenous people were under-represented.

- The discussions began with what participants valued about living in Lakes Entrance and establishing desired goals for the future of the town.
- Participants were then asked to discuss the most recent flood they could remember and highlight on a map of the town where they had previously observed flooding.
- They were then presented with two hypothetical future flooding scenarios, developed during the workshop: 25 days of low-level (1:10-year) floods in a year; and two 1:100-year floods in a year. These scenarios prompted discussion of what kinds of triggers were meaningful to participants (the frequency and extent of flooding they considered disrupts the town functioning, and what level of flooding would signal a level of social and environmental change different from the present).
- Participants were then asked to suggest the kinds of responses they would expect in the event of such a change.

7 This pathways sequence with triggers is summarised in figure 71. The process and the outcomes have yet to be implemented.

Source: Adapted from Barnett et al (2014)

Figure 71: Pathway sequence showing triggers and areas affected and policy steps designed for Lakes Entrance, Victoria, Australia



Source: Barnett et al (2014), with permission

These triggers, however, all imply a level of damage has to happen before adaptation starts, which may be tolerable today but not in the future. Furthermore, having several different types of triggers will be more robust because they can validate what is being experienced.

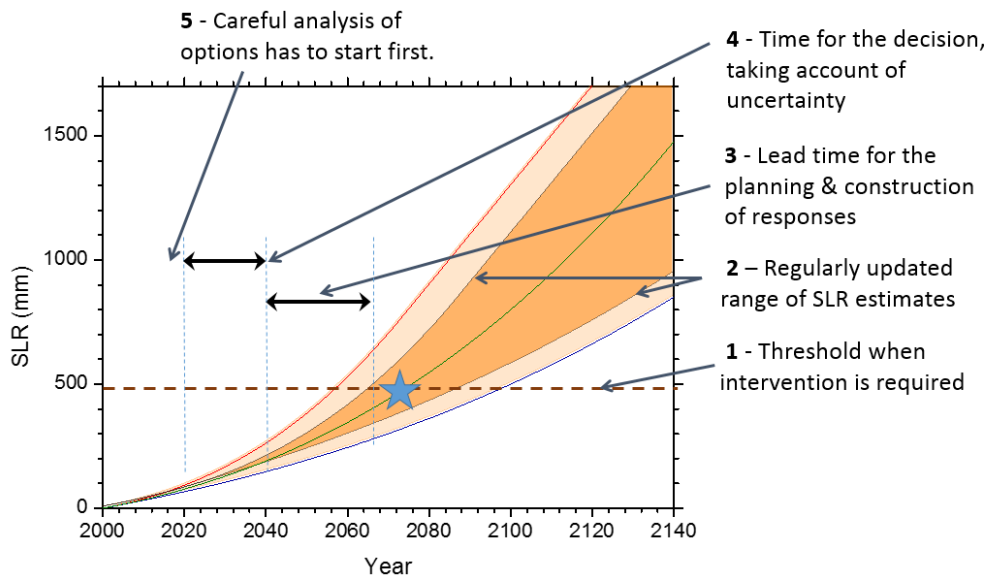
Examples include:

- in a flooding context, the average river summer discharge may be appropriate, since it appears earlier in the policy and impact chain and is less sensitive to extreme events. It could also be sufficiently relevant to a policy objective (eg, water quality or river navigation)
- in a sea-level rise context, frequency of coastal inundation reaching nuisance levels (before a critical damaging threshold is reached) such as coastal storm inundation of land five times in 10 years; or critical access road inundated X times per year; or for coastal erosion, the dune-line reaching X metres from a house (eg, Mahanga E Tu case; appendix B).

The usefulness of the signals and triggers (decision points) based on measures of sea-level rise or coastal inundation frequency is that they can include a buffer that gives lead time. This allows course correction to be managed in the particular timeframe relevant to the hazard exposure and risk, and the implementation time (figure 72).

Typically, infrastructure projects (eg, stormwater, water supply, sewage, electrical utilities) have long lead times, for replacement, redesign and removal, and for consents where required. Change needs to be anticipated through earlier signals to make sure that adjustment periods are available and can be managed in the least disruptive manner for communities and councils.

Figure 72: Lead time working back (1–5) from a given adaptation threshold



Note: SLR = sea-level rise. Source: Adapted from Reeder and Ranger (2010)

To enable the adaptive planning strategy to operate over long timeframes, and to address uncertainty about the future, triggers need to be designed, with sufficient lead time, that can define the conditions under which the current option or pathway will not meet the plan objectives at the adaptation threshold.

Signals and triggers (decision points) will form part of the monitoring system to help gauge whether the objectives are still being met or whether a change of course to different options, or another pathway, is needed before the adaptation threshold is reached.

10.1.2 Implementation frameworks and measures

Managing change and uncertainty in the different decision-making contexts (whether statutory or non-statutory, in whatever area of council operations – asset management, Resource Management Act 1991 (RMA) policy or consents, building consents – and at whatever governance level) is a challenge for those advising on and making decisions in local government. While certainty has long been an expectation that communities and property owners have valued highly, they also have expectations that the hazard risks will be identified in a way that can be avoided and adapted to given experience with damaging climate events. Planning has relied on the use of static representations of the future in space and time (eg, one scenario, a hazard zone or line on a map, or a fixed seawall). In many circumstances, these will not be flexible in the future to allow adjustment to changing risk. This is because those protected will have expectations of further protection and investment landward of them, which will increase exposure to risk over time, and adjustments will raise issues of implementation and who pays. Understanding by communities of the limitations of static measures in a changing climate context is a critical requirement underpinning the implementation of this guidance.

The RMA, the Local Government Act 2002 (LGA) and the Civil Defence Emergency Management Act 2002 (CDEMA) require management and reduction of risk where this is

foreseeable. The foreseeability of sea-level rise implies a need for greater flexibility in the way of planning, investment instruments and any supporting policies (eg, role of insurance or support for managed retreat) are designed and used.

A key part of implementation is the financing of adaptation. The types of adjustments that will eventually be necessary are unprecedented and will have significant implications for the ability to pay and what financing methods are used. Because sea-level rise is foreseeable, this gives a window of time to consider whether the current financing instruments will be adequate or whether new ones will be needed to ensure a planned response to the consequences before they appear.

Cost for councils will include costs for adaptation measures and of delivering services for which they are responsible. Costs to communities will include immediate damage and adjustment costs, costs of retreat in some locations and personal costs of loss of place and culture. Communities at local levels not directly affected will, depending on how the adaptation is funded, potentially bear increased costs to pay for regional or local responses and impact costs. Inevitably, central government will be asked to bear costs where the ability to pay at the local level is challenged. Where impacts fall on the private sector, there will be business interruption costs and potentially retreat costs in some areas. These transfers of risk will be felt as higher taxes, rates and the cost of insurance.

Such risk transfers that happen by default, usually after extreme events, raise questions about the role of insurance.

BOX 20: INSURANCE PRINCIPLES

The report *Risk Financing in Local Government* commissioned by Local Government New Zealand (2016a) identifies the following principles of insurance that are relevant in the context of responding to coastal hazards and climate change, in particular, the financing of adaptation.

- **Homogeneity.** There must be a sufficient number of subjects for insurance of a similar class to produce a reliable average of loss experience. (This can only be calculated after the fact, because there is no human experience of the impacts of sea-level rise.)
- **Calculability.** It must be possible to calculate the chance of loss, either mathematically or through past experience. The greater the uncertainty surrounding the probability of loss occurrence the higher the premium loading for this factor. (Sea-level rise is a new risk, and historical experience cannot be used to calculate the probability of loss.)
- **Fortuity.** Although it is known that losses will occur and that the frequency can be measured, a specific loss must be unforeseen. (Losses from sea-level rise are foreseeable.)
- **Insurable interest**. Insurance is designed to preserve the financial interest of the insured party, and if that party cannot show such an interest (and therefore potential loss) then insurance cannot be obtained. (Those affected will have an interest.)

Note: Comments in brackets are Guidance author emphasis.

Calculability and fortuity appear, therefore, to exclude insurance against losses from coastal hazard risk and sea-level rise. Furthermore, the Earthquake Commission excludes loss from incremental loss as envisaged by sea-level rise and, arguably, increasing frequency of storms and erosion at the coast and the effect of king tides. Therefore, whether current risk transfer policy settings through insurance are sufficient to cover unavoidable risks will need further investigation. Alternative insurance mechanisms that could be used, the barriers and enablers

for adopting mechanisms that enhance the safety and resilience of coastal communities in New Zealand and financing mechanisms for adaptation will also require further investigation.

The Local Government New Zealand (2016a) report makes suggestions about other risk transfer products, including collectives (pools of councils, eg, Local Authority Protection Programme Disaster Fund and RiskPool), captives (insurance company ownership by the insured), catastrophe bonds, risk swaps, contingent capital, contingent risk and finite risk. Some of these are only triggered after the fact so will not motivate risk avoidance and reduction through adaptation, and may increase risk exposure from coastal hazards and sea-level rise.

Other aspects of insurance may come into play that emphasise the limits of insurance for addressing losses. Insurance is based on a one-year contract, which means foreseeable risks like sea-level rise will be factored into risk ratings at the coast as pressure comes on from the reinsurers. Greater incidence of storm events at the coast will also become a greater call on the Earthquake Commission system and its ability to compensate, which arguably could exclude such foreseeable events. This puts the focus back on those with the responsibility to avoid and reduce the hazard risk — local government and property owners.

As coastal hazard risks compound around New Zealand, a likely future issue for local government will be financing and capacity for adaptation. This suggests that all levels of government will need to be involved in addressing the risks and motivating anticipatory adaptive planning approaches as the key to coastal hazard risk management. For councils, insurance instruments are available that can cover their own liability and business interruption, but private property owners may be outside these measures. This is especially true with respect to transformational adaptation to avoid foreseeable risks like SLR, and new policy and funding instruments are likely to be required.

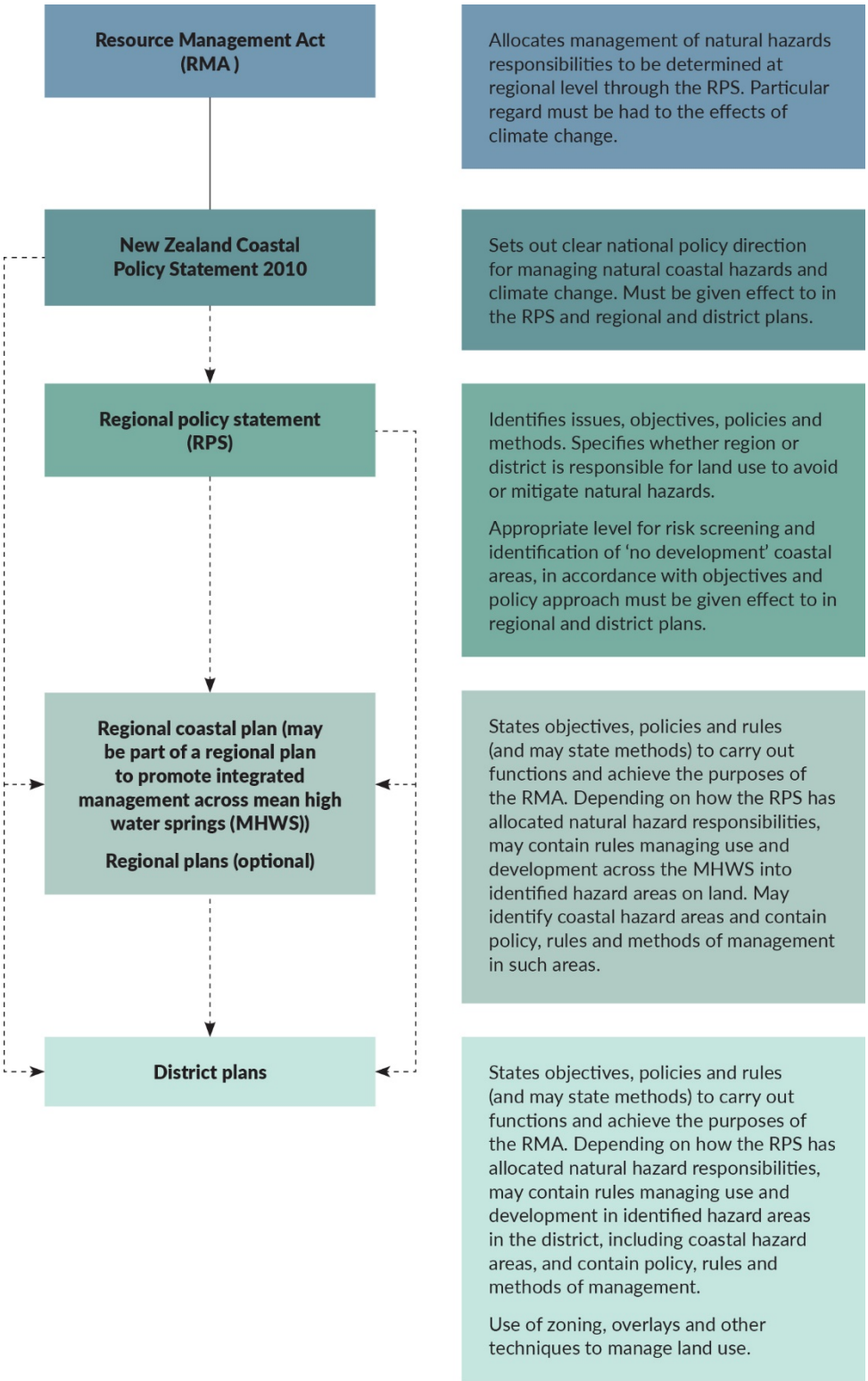
10.2 Adapting to increasing coastal hazard risk through planning

10.2.1 Planning frameworks

A range of planning frameworks and more detailed techniques are available to help in reducing coastal hazard risks, as set out in figure 73 and tables 24–26.

Figure 73 shows the key RMA policy statements and plans, and their relationships. These have legal force, and their preparation and review are formally required under the RMA. They have specified community and stakeholder process requirements as part of their development, and there are formal opportunities to challenge and test their contents. The RMA section 32 evaluation, which must accompany their public notification, involves tests of appropriateness of objectives in achieving the sustainable management purposes of the RMA, the effectiveness and efficiency of the provisions in achieving the objectives, and the risks of acting or not acting if the information leading to the provisions is uncertain or inadequate.

Figure 73: Relationships for coastal hazard management under Resource Management Act 1991 policy and plans



Note: MHWS = mean high water spring tide; RMA = Resource Management Act 1991.

To help local government agencies to carry out their wider statutory functions, and to provide the community with opportunities to become involved in less formal processes, local government has developed and now undertakes planning outside the statutory planning framework of the RMA. The range of planning that local government undertakes and the types of plans prepared are set out in table 25. Some are required by the RMA, the LGA or, for example, the Reserves Act 1977, but others are less formal and contribute to statutory plans

and overall integrated management of natural and physical resources, for example, coastal hazard plans.

The plans in table 25 are one of the vehicles through which adaptive planning can take place and within which the more specific planning methods set out in table 26 can be applied. Together, they can help address the consequences arising from the hazard, and risk and vulnerability assessments. Non-statutory plans are usually where community aspirations are often best identified and developed, but many of the key elements of the non-statutory plans will need to be carried through into a statutory framework in an RMA plan to be effective or enforceable.

The regional level is the most appropriate for hazards identification and high-level risk screening (see chapter 8). It is also the level at which the wider (regional) community hazard management objectives will be set. Through the regional policy statement (RPS), this will include the regional representation of the response to national level policy (New Zealand Coastal Policy Statement 2010 (NZCPS 2010) objectives and policies (Department of Conservation, 2010), as in figure 73), and the allocation of hazard management responsibilities between the regional and district councils. The RPS may identify exclusion areas for new urban development. Spatial planning, if undertaken at regional level, may also be expressed through the RPS by identifying areas suitable or unsuitable for growth and intensification.

Guiding practice

In accordance with the New Zealand Coastal Policy Statement 2010 (NZCPS 2010), the regional strategic approach to coastal hazard risk management is to avoid and reduce risk, and, thus, inappropriate development (Department of Conservation, 2010). This includes a structured approach (Policy 7, NZCPS 2010) that takes into account Policy 25 of the NZCPS 2010, to avoid increasing the risk of social, environmental and economic harm over at least the next 100 years (eg, Auckland regional policy statement (RPS) example in box 21). The RPS is the appropriate level to provide objectives, policies and methods that must be applied at the district level. Areas or situations where new greenfield urban development should not be allowed need to be identified and have policy implemented to ensure development in such areas cannot proceed.

A combined strategic approach may need to be developed to achieve RPS objectives (eg, Wellington Region Natural Hazards Management Strategy in box 21).

Note: The default provision for control of the use of land for natural hazard avoidance or mitigation (unless the RPS specifies otherwise) lies with regional councils under the Resource Management Act 1991 section 62(2).

BOX 21: EXAMPLES OF DIFFERENT LEVELS OF COASTAL HAZARDS AND RESILIENCE PLANS

1. Regional policy statement (RPS) example

Auckland Unitary Plan: council's decision version (Auckland Council, 2016)

RPS Chapter B.10 – Ngā tūpono ki te taiao – Environmental risk

B.10.1 Issues

Natural hazards and climate change

Auckland's growth will increase pressure to develop areas more susceptible to natural hazards. There may be conflict between where people want to live and where they can live safely, particularly in some coastal areas. Some existing development, including infrastructure, is already located on land that may be subject to natural hazards. This needs managing to ensure that the risk is not increased. Climate is changing, in both the short and long term. This creates significant risks, (including exacerbating natural hazards), uncertainties and challenges for Auckland. How the region manages land use in response to climate change will determine the resilience of Auckland's economy, environment, and communities in the future.

B.10.2 Natural hazards and climate change

B.10.2.1 Objectives

(1) Communities are more resilient to natural hazards and the effects of climate change.

(2) The risks to people, property, infrastructure and the environment from natural hazards are not increased in existing developed areas.

(3) New subdivision, use and development avoid the creation of new risks to people, property and infrastructure.

(4) The effects of climate change on natural hazards, including effects on sea-level rise and on the frequency and severity of storm events, is recognised and provided for.

B.10.2.2 Policies

Management approaches

(7) Avoid or mitigate the effects of activities in areas subject to natural hazards, such as earthworks, changes to natural and built drainage systems, vegetation clearance and new or modified structures, so that the risks of natural hazards are not increased.

(8) Manage the location and scale of activities that are vulnerable to the adverse effects of natural hazards so that the risks of natural hazards to people and property are not increased.

(9) Encourage activities that reduce, or do not increase, the risks posed by natural hazards, including any of the following:

- (a) protecting and restoring natural landforms and vegetation
- (b) managing retreat by relocation, removal or abandonment of structures
- (c) replacing or modifying existing development to reduce risk without using hard protection structures
- (d) designing for relocatable or recoverable structures
- (e) providing for low-intensity activities that are less vulnerable to the effects of relevant hazards, including modifying their design and management.

BOX 21: EXAMPLES OF DIFFERENT LEVELS OF COASTAL HAZARDS AND RESILIENCE PLANS

(10) Encourage redevelopment on land subject to natural hazards to reduce existing risks and ensure no new risks are created. by using a range of measures such as any of the following:

(a) the design and placement of buildings and structures

(b) managing activities to increase their resilience to hazard events

(c) change of use to a less vulnerable activity.

Coastal hazards

(13) Require areas potentially affected by coastal hazards over the next 100 years to do all of the following:

(a) avoid changes in land use that would increase the risk of adverse effects from coastal hazards

(b) do not increase the intensity of activities that are vulnerable to the effects of coastal hazards beyond that enabled by the plan

(c) in the event of redevelopment, minimise natural hazard risks through the location and design of development

(d) where it is impracticable to locate infrastructure outside coastal hazard areas, then ensure coastal hazard risks are mitigated.

RPS Chapter B.11 – Monitoring and environmental results anticipated

Table B.11.9 (B10) (related to B.10 – Environmental risks) (extract)

Reference	Objective	Indicator
B.10.2.1(2)	The risks to people, property, infrastructure and the environment from natural hazards are not increased in existing developed areas.	Personal injuries and property damage in developed areas resulting from natural hazards and the effects of climate change do not increase over time.
B.10.2.1(3)	New subdivision, use and development avoid the creation of new risks to people, property and infrastructure.	Structure planning and plan changes make explicit provision for natural hazards and the effects of climate change.

2. Wellington Region Natural Hazards Management Strategy

As part of the development of the proposed Natural Resources Plan, a draft Wellington Region Natural Hazards Management Strategy has been developed (Method M3, see below) in partnership with five city and district councils and the Wellington Region Emergency Management Office (WREMO).

The aim of the strategy is to guide research and planning for hazards toward a vision: The communities of the Wellington region work together to understand and reduce risks from natural hazards, to survive and thrive in a dynamic world.

The objectives are:

- for natural hazards and risks to be well understood
- for planning to take a long-term risk-based approach
- to have an agreed set of priorities to reduce the risks from natural hazards

BOX 21: EXAMPLES OF DIFFERENT LEVELS OF COASTAL HAZARDS AND RESILIENCE PLANS

- for consistent approaches to be applied to natural hazard risk reduction.

Method M3: Wellington regional hazards management strategy

Wellington Regional Council will work in partnership with city and district councils and stakeholders to develop and implement a Wellington regional hazards management strategy. The purpose of the strategy is to facilitate a consistent approach to managing natural hazards between local authorities in the region.

Source: www.gw.govt.nz/assets/Plans--Publications/Regional-Plan-Review/Proposed-Plan/Chapter-6-Other-methods.pdf

After gathering community knowledge as part of step 1, and when areas have been identified as at risk of being affected by coastal hazards, a local authority, in association with the community, should become involved in the processes set out in this guidance. The adaptive planning process begins after hazards are identified and understood, community values have been identified, objectives set and a vulnerability and risk assessment undertaken (steps 1–4, figure 69).

Step 5 (figure 69) is where options for the future are scoped and described, and possible adaptive pathways are identified that can meet the objectives. The options are identified through planning processes that contribute to the development of any or all of the types of plans included in table 25. Note that some of the plans described are special purpose and/or limited in spatial extent. Some of the plans may be subset exercises, contributing to broader community planning exercises (eg, asset and reserves management plans). The decision on the type of planning undertaken, and its resourcing, lies with the local authority involved.

Once possible pathways have been identified, they can be evaluated at step 6 (figure 69) and methods described earlier in this chapter can be used to identify, analyse and make decisions on the preferred pathways (developed at step 5 and evaluated at step 6). As part of this process, signals and triggers (decision points) need to be designed for monitoring the effectiveness of the pathways. Step 7 involves bringing together the preferred adaptive planning strategy, which can be embedded into the statutory planning documents (and any other relevant documents, such as collaborative planning agreements or asset plans), as part of the implementation at step 8.

Typically the specific planning methods and techniques in table 26 will be considered at the options evaluation stage of the planning process where they can be included, or at least taken into account, in the pathways developed using the DAPP approach. Then they can be included in implementation planning for the range of pathways assessed. This means that the questions around implementation, feasibility and monitoring of early signals and implementation triggers (decision points) for future adjustment can be addressed.

Given the 'at least 100 years' basis of the NZCPS 2010 coastal hazards management policy, the DAPP process will need to be embedded in the statutory planning framework in a way that provides sufficient certainty over time for continuation of policy in a long-term planning approach. It will also need to enable the adaptive pathway, the signals and triggers (decision points) to be determined when adjustments are required to a new pathway (eg, like when objectives are no longer likely to be met). A statutory plan, whether at district or regional level, therefore needs to contain sufficient information about the adaptation plan or strategy itself to ensure that this happens. For example, the statutory plan should include a description of the issue, a brief outline of the information and process that led to the specific provisions, and

policy provisions that underpin the approach being taken at present. If appropriate, it should foreshadow and enable a shift to an alternative pathway.

Given the 10-year plan review requirement, it is likely that a transition to a new pathway, if it involves policy adjustment and/or new rules, would be subject to formal evaluation through the normal RMA plan review process or a plan change.

Details of the adaptive planning strategy, developed using the DAPP approach, may be incorporated in a district or regional plan through an appendix or schedule. There it can provide context and guidance for planners and decision-makers and be reviewed at the time of plan reviews or when the triggers in the adaptive plan signal that it no longer meets its objectives (taking into account implementation lead time).

As yet, no comprehensive examples of these approaches are in statutory plans, although the Mapua–Ruby Bay example (see box 6, in chapter 2) contains some of the elements. The DAPP was also used for the adaptive pathways developed by the Greater Wellington Regional Council for the Hutt River flood management plan (box 18).

Statutory planning instruments manage land use and development. In most cases, local authorities will have other policy and plans that operate alongside the statutory plans and provide for asset management and other investments or targets that will integrate with the DAPP process (eg, the Clifton to Tangoio Coastal Hazards Strategy 2120 (Coastal Hazard Committee, 2016)). A council's civil defence and emergency management (CDEM) functions and responsibilities will also sit alongside and contribute to hazard management in coastal areas.

10.2.2 Choice of methods and techniques

Table 26 sets out planning methods and techniques that can be used in the lead up to, and in, statutory planning. The choice of method(s) will depend on the situation, the scale of the area and its current development, the objectives and policies and the community's input. The methods described are all directed at the management of development through statutory (enforceable) processes and/or community contributions through education, monitoring and active management of coastal defences. Developing the right balance of methods to achieve the council's and community's objectives can be complex. Local government is building expertise in these areas, and case law (see appendix B) provides support for developing practice.

Finally, table 27 sets out coastal protection techniques that may be included in the development and analysis of options and adaptive pathways. Particularly where there are existing hard protection structures, decisions will be required about their effectiveness and long-term future, and, if appropriate, at what stage they will need either further investment or abandonment. If they are to be abandoned or removed, planning for a new, restored and more dynamic coastal margin must be foreshadowed and enabled.

Table 25: Types of plan and planning processes available to local government to help in managing coastal hazard risks

Types of plans and planning processes	Description	Application
Spatial planning, growth planning	Method of large-scale, long-term regional or sub-regional planning, generally undertaken under the Local Government Act 2002 (LGA) mandate primarily to address urban planning issues, but closely linked to regional policy statements (RPS). Often form the basis for district plans and may influence regional plans. May be undertaken by a single local authority (eg, Auckland Council) or a group of local authorities, usually under the leadership of the regional council (eg, Wellington, Canterbury). The plan takes a long-term integrated approach to the future of an (urban) region, providing for infrastructure, urban growth and change and other key values and attributes in its geographical context. This provides a framework for ongoing integrated land use and asset planning and management through plans required under the LGA and Resource Management Act 1991 (RMA).	• Key context for consideration of long-term management of land resource and infrastructure in terms of changing coastlines and coastal processes. • Expected to take into account national policy through the New Zealand Coastal Policy Statement 2010 (NZCPS 2010; Department of Conservation, 2010) and its strategic planning and other policies. • Involves constraints mapping (which can include hazard and inundation maps developed on the basis of a range of scenarios). • While there may be a 30–40 year driver to increase urban capacity, assessment must take a longer view, because the life of assets and investments must be considered and adjusted in the future. • Useful for both greenfields and existing areas. Will highlight: – areas to be managed for change on the basis of retreat or 'down zoning' to be staged over time – areas where new development or intensification will or will not be appropriate – areas where new greenfields or intensified development may be permissible. • Cost and vulnerability of future protection can be carefully considered and factored into the assessment of options for high-valued existing areas. • Development areas are considered in functional terms, that is, can they be accessed and serviced over long timeframes, and the maintenance costs of community-owned assets can be taken into account in the long term. Note: The Resource Legislation Amendment Bill 2015 and the National Policy Statement on Urban Development Capacity require planning for efficient development capacity for housing and business activities over the next 30 years, and their location, timing and sequencing. Both will require spatial planning.

Types of plans and planning processes	Description	Application
Regional strategies – such as natural hazards strategies	Special-purpose, single-issue planning or strategies, developed on a regional basis by a combination of local government units. For natural hazards planning, can be undertaken through LGA, RMA or civil defence and emergency management (CDEM) (risk reduction) mandates.	• Can input into other statutory responsibilities. • On basis of shared interest (and costs), can contribute to improved information on natural hazards and its presentation and availability. Ensures equal treatment of public information, and provides for agreement on analytical techniques and planning methods. • Forms basis for equitable treatment of community interests and more (usually regional) standardisation of planning approaches.
Regional policy statements* – coastal or natural hazard policy	RPSs as required under the RMA for every region. Objectives, policies and other methods (which can include methodologies, standards and mapping techniques) that must be given effect to through regional and district plans.	• RPSs are required and must identify (and by implication address) the region's issues through seeking to achieve integrated management of natural and physical resources. • Must give effect to the NZCPS 2010 (and any other relevant national policy statements (NPSs)) • Can provide directive policy, and vary approaches over the region's areal extent (ie, to take in different geographic circumstances). • Integrates iwi management plans (where RMA section 61(2A) applies). • Determines who is responsible (ie, the regional or territorial local authorities) for the control of the use of land to "avoid or mitigate natural hazards or any group of hazards" (RMA section 62(1)(i)(i)). • Must set out methods to monitor its own effectiveness. • Can be a powerful tool in the adaptation toolbox, because the provisions need to be given effect to through district and/or regional plans. Note: The default provision for control of the use of land for natural hazard avoidance or mitigation (unless the RPS specifies otherwise) lies with regional councils, under RMA section 62(2).
Regional plans – regional coastal environmental plan* or a coastal or natural hazards section of a regional plan	Objectives, policies, rules and other methods that apply to the planning and management of the region's natural, and in some circumstances, regionally significant physical resources, under the RMA.	• Must give effect to the NZCPS 2010 and any other relevant NPSs. • Must give effect to the relevant RPS. • Integrates iwi management plans (where RMA section 66(2A) applies) • Can provide for integrated coastal management (building on NZCPS 2010 and relevant RPSs). • Can set policies (objectives and policies) that apply differentially across a region, for example, through coastal natural hazards mapping.

Types of plans and planning processes	Description	Application
		• Can indicate the basis for staged retreat through policy across successive plans. • Can set standards to be achieved through rules (eg, setbacks, floor levels, construction types such as relocatable buildings). • Rules have force of statutory regulations. • Can manage infrastructure directly through rules, which can in turn manage buildings and development, for example, excluding onsite wastewater treatment and underground infrastructure, coastal protection works excluded from defined areas, development excluded from defined areas. Must be based on the purpose of avoidance or mitigation of natural hazards. • Land use and building rules applied through regional plans automatically cancel existing use rights in defined areas (ie, resource consents are needed at least every 35 years, or less if specified, to remain on sites). This can be an important tool when risks are clearly increasing rapidly in any particular coastal area.
District plans*	Objectives, policies, rules and other methods to achieve integrated management of the effects of use, development and protection of land and associated natural and physical resources.	• Must give effect to the NZCPS 2010 and any other relevant NPSs. • Must give effect to the RPS and not be inconsistent with relevant regional plans. • Integrates iwi management plans (where RMA section 66(2A) applies). • Includes planning to avoid or mitigate natural hazards (at least to the extent provided under the RPS mandate). • Can indicate the basis for staged retreat through policy across successive plans. • Can set policy (objectives and policies that apply differentially across a district, eg, through natural hazards overlays, including risk-based overlays). • Establish development rights through zoning and associated permitted, controlled, discretionary, non-complying and prohibited activities. • Can set standards to be achieved through rules (eg, setbacks, floor levels, density, intensity, redevelopment controls and construction types, such as relocatable buildings). • Can manage all land uses (including infrastructure, except where designated) directly through rules. Can be used to incentivise land-use change through identifying and providing for no- or low-hazard development areas.

Types of plans and planning processes	Description	Application
Precinct, area or structure plans	Plans for development or redevelopment areas (greenfields or brownfields), integrating infrastructure, open space, protected places and areas for various types of development. Generally at suburb scale or smaller. Integrated into district plans and subject to detailed statutory provisions.	• May be helpful by identifying areas for protection (eg, buffers, setback areas, significant open space areas where land is low lying or low density, or building-excluded areas) and infrastructure corridors and temporary refuge areas (eg, flood hazard or tsunami refuges). • Involves constraints mapping. • Involves integrated long-term consideration of community needs, including infrastructure and connectivity. • Areas generally identified on the basis of development opportunities or character protection. Could, however, be used as a basis, for example, for staged retreat or phasing out of development in the long term or for progressive investment for coastal or other protection.
Special purpose area plans	Special-purpose, single-issue plans or strategies, developed within a district to address specific place-based issues. For natural hazards planning, can be undertaken through LGA, RMA or CDEM (risk reduction) mandates.	• Can input into other statutory responsibilities. • On basis of shared interest (and costs), contribute to improved local information and its presentation and availability on natural hazards, provides useful basis for community engagement and problem solving, and for agreement on analytical techniques and planning methods.
Asset management planning*	LGA requirement for forward planning for local government assets (roads, infrastructure – three waters, parks and reserves, other assets such as community-owned coastal protection). Undertaken through long-term plans and 30-year infrastructure strategies.	• Essential underpinning for use and development of urban and rural areas. • Requires long-term focus. • Planning needs to integrate with land-use planning and needs to take into account costs and difficulty of maintaining levels of service over time in coastal areas.
'Community futures' or 'community vision' planning	Highly participatory but informal planning exercises now frequently carried out within the LGA framework, led by territorial authorities or community boards, to help with framing the statutory RMA and LGA planning processes. Take many forms. No direct statutory status.	• Useful method of two-way engagement/information provision between council and identifiable communities. • Issues driven from grass-roots level and may contain many ideas, techniques and commitments between community and council. Usually contain spatial components. • Important role in identifying, foreshadowing and beginning to address trends and changes both environmentally and socially. • May identify coastal hazard risk and, as not time-bound, may be useful first step to community understanding.

Types of plans and planning processes	Description	Application
		• May start the dialogue on the needs of future communities, including long-term adaptive planning.
Collaborative planning	Form of planning local government undertakes with iwi and key infrastructure providers (eg, New Zealand Transport Agency and KiwiRail).	• Involves close relationships and development of agreements between local government and the relevant stakeholder(s). • May have a spatial dimension, and may include memoranda of understanding or other agreements. • Iwi have critical interest in the coastal marine area (CMA) and the land–sea interface, and may have a range of preferred management tools. • Key infrastructure providers may have assets (including lifeline assets) that will become at risk under different scenarios. • Plans and agreements need to interface effectively with other local authority planning, particularly in terms of coastal hazards.
Reserves management planning*	Planning requirement under the Reserves Act 1977. May extend to policy on esplanade reserves and strips and their management under the RMA.	• Where reserve areas are alongside the CMA, can be used to develop and apply key approaches to hazard management, including management of areas that function, or may be developed to function, as natural defences.

Note: Asterisk in left-hand column signifies plans that are required by statute.

Table 26: Planning methods and techniques available to local government to help in managing coastal hazard risks

Specific planning methods and techniques	Description	Application
Zoning	Provides identified geographic areas for use, development, protection, and for change through policy and rules.	• Requires a clear policy basis for any rules and other enforceable methods. • Technique can be tailored to suit circumstances (ie, can prevent intensification or exclude areas from development or redevelopment). • Tendency is, however, towards 'highest and best uses', and, while zoning provides development rights, it is often very difficult to 'down zone' to reduce development intensity without immediate hazard threat or risk. • Because of 'existing use rights', zoning cannot be used to induce or force change (such as raising floor levels on existing dwellings).
Identified hazard lines or overlay areas	Identifies areas on the basis of hazard risk exposure and applies more restrictive rules in such areas.	• Requires a clear policy basis for any rules and other enforceable provisions. • Technique can be tailored to suit circumstances (ie, works together with zoning, and can be used to apply more restrictive controls in areas of higher risk exposure). • Can be the basis for areal application of some of the methods below.
Designations	Used to establish and protect works and networks by approved organisations, usually public but sometimes community-based organisations. Note: community-based organisations are not known to be requiring authorities for designations for coastal protection; however, a possible model is found in community irrigation and flood protection schemes.	• May be used to provide for infrastructure, which may include coastal protection or buffer areas. • Releases the activity or work from the need to comply with district plan provisions. • Applied alongside the Public Works Act 1981, which enables compulsory acquisition of land for 'public' or community purposes. • Other than for local authorities, there are strict requirements and numerous hurdles to become a requiring authority and to initially obtain RMA approval for land or works that may be subject to designations. Used for flood protection works in some circumstances. May have more coastal application in the future.
No subdivision areas	Areas in district plans identified on the basis of zoning or overlays in district plans (or potentially regional plans).	• Applies high minimum lot sizes (eg, as with rural zoning), or prohibits further subdivision. • Requires a policy basis, such as natural hazard risk exposure (or natural character protection). • Subdivision invariably carries development rights for new dwellings, and so limiting subdivision limits development opportunities. • Potentially useful as a technique for limiting development exposed to coastal hazards.

Specific planning methods and techniques	Description	Application
Excluding particular activities from identified areas	Rules that apply to discourage or limit specified activities in identified hazard areas – using the full range of RMA activity classifications, including prohibited activities.	• Often applied to lifeline or emergency service and support type activities, or activities that have enhanced effects should they have to be shifted or are abandoned, or succumb to direct exposure to natural hazards – such as hospitals, emergency service facilities, fuel storage areas, energy centres (power stations and substations). • Rules can be used to provide barriers to establishment, expansion or intensification of such activities or facilities. • Activity status, in association with hazard lines, can ensure that development occurs only in accordance with a consenting process and subject to conditions, or further development is prohibited. For example, restricted or full discretionary activity status can provide the opportunity for a consent authority to impose specific controls through conditions on building location or design in specified zones or certain sites, or to decline consent. Prohibited activity status means that no consent can be sought for specified activities.
Specifying minimum floor levels	This technique involves rules in plans that specify minimum floor levels, or conditions that may be attached to resource consents in identified hazard areas.	• The technique is potentially useful for areas of high groundwater or surface ponding (eg, behind dune systems). • It requires an understanding of groundwater and flood levels. • It can provide for transitional use of residential land that may eventually succumb to coastal inundation. • It is not useful in areas of more rapid coastal retreat, or areas of flowing flood or tidal water, as it only provides for ponding-type surface flooding.
Specifying types of construction and building design and use	This technique is most likely to be applied at resource consent stage, in deeper floodable areas, or through a building consent where no resource consent is required.	• The technique is more common overseas and involves 'permeable' ground floors (ie, water can move into and through the building) and limitations on the use of ground floors or basements for non-habitable activities. It can encompass designs able to be 'jacked-up' in the future. • Alternatively, it can involve flood doors to seal ground floors up to a certain height. • As with the above technique, it is limited to ponding areas and is not suitable in areas of flowing water. • Some of the techniques can be applied to retrofit and future-proof existing buildings for a period. • Access to buildings in such circumstances may be an unresolvable problem.

Specific planning methods and techniques	Description	Application
Specifying relocatable buildings	This technique can be captured within zoning or overlays in coastal areas that are anticipated to succumb to coastal erosion or inundation within the life of the building.	• May be applied in the context of managed retreat, that is, allowing for interim use of coastal land. • Requires relocation once a trigger is reached (eg, distance of mean high water spring tide from building edge). • Requires consideration of access and practicable ability to relocate. • Also limits site infrastructure, such as onsite wastewater management, outbuildings, fences, paths. • Involves a covenant or bond to ensure relocation will be undertaken. • In some circumstances, an applicant must demonstrate the permanent availability of a site to relocate to.
Temporary development or land-use consents	This technique can be captured within zoning or overlays in coastal areas that are anticipated to succumb to coastal erosion within the life of the building.	• Consents are subject to a specified duration on the site. Consent must be renewed to remain. • The technique does not require trigger circumstances, but otherwise the considerations in the box above apply.
Prohibited activities	This technique can be incorporated in zoning or overlays in coastal areas.	• Can be used to constrain development or types of activities in certain circumstances, for example, hard protection structures on public or private land. • No consent applications can be made for the specified activities in the identified locations.
Land information memoranda (LIM); project information memoranda (PIM)	Information concerning land parcels (LIM, under the Local Government Official Information and Meetings Act 1987) and existing buildings (PIM, under the Building Act 2004) is available on request from territorial local authorities.	• Provides information about the exposure of land or buildings to natural hazards (if such information is known to the local authority). A LIM may not contain this information if it is indicated on the district plan. • For buildings, the PIM may indicate site risks or previous exposure and response to hazard events. • These techniques are information provision only. They alert potential purchasers to potential risks.

Specific planning methods and techniques	Description	Application
Covenants, easements and consent notices	These are techniques that can be attached to land titles, through subdivision approvals or resource consents, which can specifically limit the use of land or structures, or require ongoing performance.	• Can be used to help enforce limitations on the use of coastal land or specific and ongoing performance of conditions – for example, floor levels. • Can require action when trigger circumstances are reached, for example, to relocate or remove structures. • As they are attached to the title, they may be more effective than LIMs in conveying information about risks or hazards on a land parcel.
Bonds	A technique applied at resource or building consent stage to ensure performance of conditions.	• Can be used when performance, such as removal of a building or structure, may incur potential environmental damage or community cost. The bond is not uplifted if performance is achieved.
Land purchase	Local authority land purchase to provide buffer areas and/or remove structures and infrastructure from natural hazard areas near to the coast.	• This method is a last resort. While theoretically possible, legislation does not currently favour designations for this purpose but may need to be increasingly used in future. • Local government is only likely to use this technique if there is national backing.
Special rating	Special rating areas may be applied under the LGA.	• Can be used to fund capital or maintenance of coastal protection. • The areas to which a special rate is applied, and the rate itself, need to be justified on the basis of benefit obtained from the council activity (or an activity transferred to a trust, incorporated society or other body, but funded by the council).
Grants and information support	Money or other support (eg, plants, advice) for community projects.	• Providing assistance and support for 'soft' options that the community can undertake. • Can be done in association with activities under the Civil Defence Emergency Management Act 2002. • Includes education and advice across a range of fronts (information services, speakers, attendance at community events).

Table 27: Coastal protection options

Coastal protection techniques	Description	Application
Hard protection structures – sea walls, rock revetments, rip rap, back-stop walls (usually buried)	Longshore solid artificial structures	• Intended to armour existing coastal alignments. • Apply at current mean high water spring tide or further into private properties. • Often associated with gradual loss of intertidal beach in front of the structure (less so if located further landward) and often create edge erosion at the ends of the structures.
Special purpose designs – sea dykes, groynes	Artificial hard structures at angle to the shore	• Intended to trap beach and coastal sediments moving longshore and build out and strengthen existing beaches (but often results in sediment deficit and erosion in areas further down-drift along the shore).
Artificial reefs and submerged breakwaters	Off-shore sub-surface protection	• Usually designed so waves break at or near the offshore structure and reduce coastal erosion in the wave shadow – may also form a salient, where the beach behind the structure accretes.
Wetland restoration, dune restoration, coastal planting	Enhancement of existing natural coastal features	• Strengthens natural coastal defences. • Requires room to move with the coast.
Beach replenishment	Import of sediment to maintain beach and coast	• Strengthens natural coastal defences. • Requires nearby source of suitable material (size, grade and colour). • Allows existing coastal processes to continue. • Needs commitment to future replenishment phases (or after a major storm).

BOX 22: ADAPTATION PLANNING EXAMPLES FROM RECENT NEW ZEALAND PRACTICE

1. Auckland Unitary Plan (AUP) (District Plan coastal hazard provisions) council decision version 19 August 2016

In the regional policy statement (RPS) for development in the coastal environment, one of the objectives is to avoid increasing the risk: "In areas potentially affected by coastal hazards, subdivision, use and development, avoid increasing the risk of social, environmental and economic harm" (chapter B8, Coastal environment, Objective 8.3.1.7).

In chapter E36 (Natural hazards and flooding) of the AUP, the relevant coastal hazard objectives (E36.2) are:

- Subdivision, use and development **outside urban areas** does not occur unless the risk of adverse effects to people, property, infrastructure and the environment from natural hazards has been assessed, and significant adverse effects are avoided, taking into account the likely long-term effects of climate change.
- Subdivision, use and development, including redevelopment **in urban areas** only occurs where the risks of adverse effects from natural hazards to people, buildings, infrastructure and the environment are not increased overall and are reduced where practicable, taking into account the likely long-term effects of climate change.

The coastal hazard policies include (E36.3):

- Ensure that subdivision, use and development on rural land for rural uses and in existing urban areas subject to coastal hazards avoids or mitigates adverse effects resulting from coastal storm inundation, coastal erosion and sea-level rise of 1 metre through location, design and management.
- Avoid subdivision, use and development in greenfield areas that would result in an increased risk of adverse effects from coastal hazards, taking account of a longer term rise in sea level.
- Ensure that buildings in areas subject to coastal hazards are located and designed to minimise the need for hard protection structures.
- Ensure that, when locating any new infrastructure in areas potentially subject to coastal hazards, an adaptive management response is considered where appropriate, taking account of a longer term rise in sea level.

- Require habitable areas of new buildings and substantial additions, alterations, modifications or extensions to existing buildings located in coastal storm inundation areas to be above the 1 per cent annual exceedance probability (AEP) coastal storm inundation event including an additional sea-level rise of 1 metre (CSI1 level). See image with vertical-hatched CSI1 layer to right of Whitford subdivision.

Activities such as providing habitable rooms in new buildings and additions of habitable rooms (greater than 25 square metres) to existing buildings within the CSI1 layer (excluding the coastal hazards area adjacent to the shoreline) require a resource consent if the floor level is below 1 per cent AEP coastal storm inundation level plus 1 metre sea-level rise. In this case, hazard risk assessments are required, including considering climate change effects over at least 100 years.

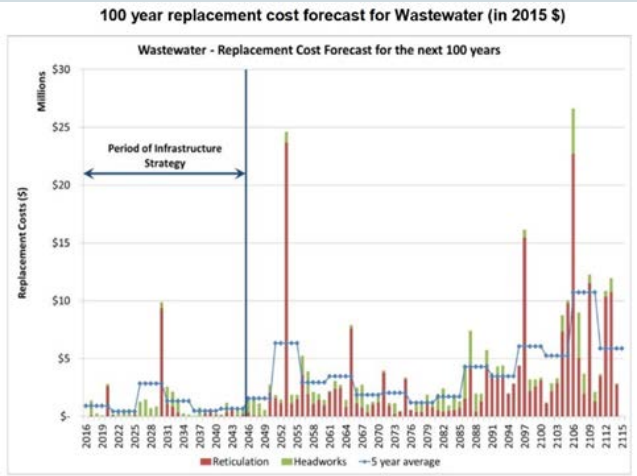
Source: http://unitaryplan.aucklandcouncil.govt.nz/pages/plan/Book.aspx?exhibit=ACDecision

BOX 22: ADAPTATION PLANNING EXAMPLES FROM RECENT NEW ZEALAND PRACTICE

2. Waimakariri District Council Infrastructure Strategy

The infrastructure strategy sets out the levels of service that council plans provide for infrastructure for the 30-year period 2015–45 and is part of the council's long-term plan (2015–25). Waimakariri, in the Canterbury region, has been one of the fastest growing districts in the country over the past 30 years, more than doubling its population. Accordingly, the average age and condition of its infrastructure is relatively new (most in-ground assets were installed since 1985, apart from the larger established centres).

This means that, for the next 30 years, the council's focus on catering for growth and meeting increasing expectations of the standard of services will provide opportunities to develop networks that are resilient to climate change and natural hazards.



The council's flood hazard mapping allows for 1 metre of sea-level rise by 2100 and a 16 per cent increase in rainfall intensity, which is reflected in revised district plan provisions. The flood hazard mapping guides development, location and floor heights for both localised and major flooding scenarios.

The council's stormwater modelling also incorporates 1 metre of sea-level rise and 16 per cent increase in rainfall intensity. All new stormwater systems are sized to manage increased flows and higher outlet levels. The potential impact of higher coastal groundwater levels on stormwater systems is one of the key climate change risks for the district, but the implications are not fully understood. For example, in Kaiapoi, pump stations are currently relied on to drain the town, but whether this can be sustained long term is unknown. Any rise in groundwater level will increase the liquefaction risk in Kaiapoi.

Source: www.waimakariri.govt.nz/__data/assets/pdf_file/0020/8444/Long-Term-Plan-2015-2025.pdf

3. Clifton to Tangoio Coastal Hazards Strategy 2120, which has a combined council committee and a technical advisory committee

The Clifton to Tangoio Coastal Hazards Strategy 2120 (www.hbcoast.co.nz) is being developed to provide a framework for assessing coastal hazards risks and identifying options for the management of those risks for the next 105 years, from 2015 to 2120. It provides a platform for making decisions about the most appropriate coastal hazard responses. It is being developed collaboratively as a cross-council approach by Hastings District Council, Hawke's Bay Regional Council, Napier City Council and groups representing mana whenua and/or tāngata whenua through a joint committee.

The *strategy scope* is to assess coastal hazards risks between Clifton and Tangoio associated with the following processes occurring over the period 2016–2120:

- coastal erosion (storm cut, trends, effects of sea-level rise)
- storm surge inundation (wave setup, runup, overtopping and sea-level rise)
- tsunami

BOX 22: ADAPTATION PLANNING EXAMPLES FROM RECENT NEW ZEALAND PRACTICE

- develop a model for funding responses to coastal hazards risks
- provide a decision-making framework to identify, evaluate, consult on and select practicable adaptation options that respond to the identified coastal hazards risks.
- implement the selected adaptation option(s) in a coordinated and planned manner that will provide the best overall outcome for the Hawke's Bay community.

4. Wellington City Resilience Plan: 'Resilient Wellington'

The aim of Resilient Wellington is to develop a strategy that will support Wellingtonians in growing their capacity to survive, adapt and thrive, no matter what chronic stresses and shocks they experience. The strategy will be a holistic, action-oriented plan to build partnerships and alliances and financing mechanisms, and will pay particular attention to meeting the needs of vulnerable people. It is managed from Wellington City, in close partnership with Porirua and Hutt City councils and the Greater Wellington Regional Council. The New Zealand Transport Agency, the Wellington Region Emergency Management Office, Wellington Electricity and Wellington Water Limited are also involved. Resilient Wellington is part of a wider global initiative, bringing together 100 cities working on improving their resilience through shared analytical tools, processes and, most of all, through shared ideas and lessons learnt. The Rockefeller Foundation has pioneered the 100 Resilient Cities (100RC) programme.

A preliminary resilience assessment has undertaken a stocktake of gaps, shocks and stresses relevant to Wellington today and in the future, an assessment of the resilience of Wellington assets to those shocks and stresses, and a collation of people's views on resilience priorities and opportunities. Sea-level rise and climate change have emerged as one of four strategic areas for the strategy development.

Source: http://wellington.govt.nz/about-wellington/resilient-wellington/about-resilient-wellington

10.2.3 Examples from practice

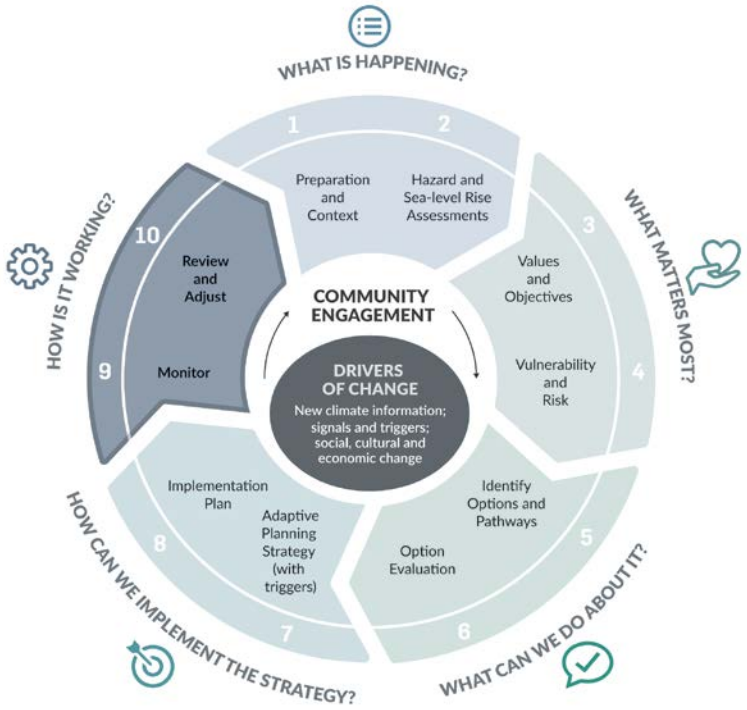
This guidance has referenced various examples of adaptation planning for coastal areas and natural hazards from a number of local authorities around New Zealand (including those referred to in boxes 6, 18 and 21). In approaching and addressing the requirements of the various statutes, local authorities are developing practice and learning from each other. The development of approaches and applicable techniques will also be influenced by the circumstances of the regional and local area, and by stakeholders and communities. Box 22 sets out further examples of emerging planning contexts within which climate change will have a significant and influential place.

Section E: How is it working?

11 Monitoring and reviewing

Chapter 11	**Chapter 11 covers:** • context for monitoring and review • involving communities in monitoring • guidance on what to monitor to support ongoing adaptation • reviewing plans and adaptation pathways.
Steps 9 and 10	**Key tasks** a. Establish the context and financing for monitoring (within the overall monitoring portfolio councils undertake). b. Determine how communities can be involved in monitoring, particularly in projects, co-management by iwi/hapū and special interest groups, industry. c. Set out objectives and methods for the monitoring programme that support the adaptation plan: • natural environmental changes and hazard events • regular assessment of vulnerability and risk • monitoring adaptive frameworks, signals and triggers (decision points). d. Decide on indicators for measuring the effectiveness of measures, plans or policies in achieving original objectives (from step 3). e. Determine how adjustments would be made in response to changes, signals, triggers and adaptation thresholds or new information.

Figure 74: Steps 9–10 in the decision cycle: How is it working? – monitoring, and review and adjust



11.1 Context for monitoring and review

The Minister for the Environment has an ongoing monitoring function relating to any matter of environmental significance to be carried out in such manner as the Minister thinks fit (section 24(ga) of the Resource Management Act 1991 (RMA)). The Environmental Reporting Regulations (under the Environmental Reporting Act 2015) include coastal and climate change related reporting under two of the five reporting domains – under the Marine topic, how climate and natural processes affect the marine environment including extreme wave and storm events; and under the Impact topic, the economic impacts caused by coastal erosion and storms that affect housing and infrastructure around the coastline.[92]

The Minister of Conservation is responsible for monitoring and reviewing the effectiveness of the New Zealand Coastal Policy Statement 2010 (NZCPS 2010), under Policy 28 of the NZCPS 2010, which includes collaborating with local authorities to collect data, and undertaking other information gathering that helps in providing a national perspective on coastal resource management trends (Department of Conservation, 2010).

Together, this will provide information on national trends for central and local government and community use.

For coastal areas, with increasing effects of climate change and sea-level rise (SLR) in the pipeline, there is also a need to build on and extend current monitoring being undertaken by local authorities.

Councils are already engaged in monitoring physical changes (eg, beach profiles, Light Detection and Ranging (LiDAR) surveys, sea levels) and the effectiveness of policies and plans and non-statutory strategies as part of the RMA, Local Government Act 2002 and Civil Defence and Emergency Management Act 2002 processes (eg, effectiveness of managing hazard risk, long-term plans, asset management plans, district and regional plans).

As climate change effects will increasingly impact on coastal areas and communities, however, there will be a need to bolster and retarget monitoring systems. An example is the progression from signals towards the triggers behind various decision points for switching adaptation pathways (eg, number of damaging inundation events, local sea-level rise threshold, or the impending failure of a particular policy or plan being used to manage coastal risk, local coping levels and/or tolerability).

Regular monitoring of the effectiveness of the current pathway option against objectives and new information (climate, sea-level rise, effectiveness of global emission reduction) or social, cultural and economic changes, may require adjustments to the decisions or objectives (and revisiting steps in the decision cycle – figure 1).

Local authorities have responsibilities under RMA section 35(3) to maintain environmental information to help people to understand the environment and the council's functions in relation to the environment. The collection and provision of information is also intended to help people to participate in RMA processes and outcomes. Under RMA section 35(5)(j), the required information includes records of natural hazards.

Local authorities also have environmental monitoring responsibilities as necessary to effectively carry out their functions under the RMA as part of the state of the whole or any part of the environment (section 35(2)(a)). An allied responsibility requires monitoring and five-yearly reporting on the efficiency and effectiveness of councils' policy statement and plan provisions (section 35(2A) RMA). Further monitoring requirements relate to consents.

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92 See www.mfe.govt.nz/more/environmental-reporting/about-act.

Regular monitoring contributes to an understanding of changing risks over time and helps with timely responses to anticipated levels of risk.

Councils have responsibilities to review their RMA policies and plans at least every 10 years under section 79 of the RMA. Even if it is found that changes are not required, the provisions must be notified for submissions and reviewed 10 years after they become operative.

11.2 What to monitor?

In a world where the climate is changing, monitoring of the nature and rates of change in the natural environment at a regional level may not readily show the long-term trends in RMA and Local Government Act 2002 decision timeframes. Thus, analysis of measured rates (trends) and magnitude of change are more appropriately provided by national agencies, but rely on local and regional gauges in the case of changes of mean sea level and frequency of inundation, along with vertical land movement. They may be expressed as frequency changes (retrospectively) or as different climate change or local SLR scenarios looking into the future.

There are requirements and roles for regional and district agencies to collect and apply information relating to the local environment at regional and local levels, however. These will most likely relate to enhanced climate impacts and processes and their effects on communities.

To be useful for long-term planning, monitoring must be undertaken over time following a consistent framework, using standardised practice methods and at identified consistent measurement locations, to yield comparable information that can reveal trends and changes. Some needs for information are likely to change over time, so adjustments and additions to the monitoring framework may be needed.

There are three general areas of monitoring that will contribute to an understanding of the changing environment: vulnerability, risk exposure and effectiveness of responses. These are outlined in the sections that follow.

Monitoring relating to climate change effects, including coastal hazards, is ideally undertaken within a regional framework. Territorial authorities, however, often have information, such as through resource consent processes, and their own specific obligations to collect and provide information. A regional framework is nevertheless beneficial to enable the development of a cohesive and consistent information base in relation to the storage, analysis and use of the information. Agreed stewardship of the data base (through regionally agreed protocols) should reduce the chance of inconsistent decision-making and variable responses to changed circumstances at district and local level.

11.2.1 Natural environment

Monitoring of the natural environment should encompass:

- collation of local and regional climate, coastal and ocean information (from national and regional sources, eg, wave information, surface temperature, winds, storms) and updated information on climate change projections for the region
- monthly and annual mean sea level, to track local (relative) sea-level rise (most councils operate a tide gauge(s)) will require protocols to ensure data accuracy is maintained and has minimal gaps
- land movement information and data from a continuous GPS recorder co-located near the main sea level gauge (if relevant to the region) and working partnership with Land Information New Zealand

- beach profiles (seasonal scales) and/or repeat LiDAR and aerial photograph surveys
- groundwater levels (especially aquifers currently exhibiting a tidal signal) and indications of changes in salinity levels (groundwater and lowland rivers)
- documentation of 'extreme' events – both weather-related and consequential events, such as flood levels, extent and depth of inundation, and episodes of erosion and deposition
- monitoring of key indicators relating to particularly vulnerable areas, such as areas of existing coastal retreat with nearby development, or that support in-ground utility networks, and levels of service performance for surface drainage and disruption to infrastructure such as roads.

The establishment and maintenance of the monitoring framework should build on current information. A gap analysis can be undertaken to identify situations where monitoring efforts should be continued and/or where they need to be enhanced or better focused.

Where areas of high risk are identified, localised monitoring of early signals and triggers is likely to be needed. Focusing of signals and triggers at the finer level of detail can help in understanding rates of change and in determining the circumstances in which to start planning and adaptive management.

Sources of information contributing to the monitoring framework will include published information, a council's own research and investigation, repeat LiDAR and aerial photographic surveys, information from resource consent or plan change requests and continuation of any established monitoring programmes. It should also encompass photographic and video records and observational material collected from the community during engagement processes or as volunteered at any time.

11.2.2 Monitoring vulnerability and risk

Monitoring of vulnerability and risk exposure will enable the range of consequences over time to be assessed. Monitoring of the physical vulnerability of assets and the exposure of assets and people to climate change related coastal hazards are the appropriate focuses for the regional and local level. This will, however, build up a picture of the national levels of exposure and vulnerability for assessing the potential implications for the national community.

Understanding the range of consequences, by monitoring an area's exposure and sensitivity to increasing coastal hazards, will enable a risk-based approach to planning over long timeframes using an adaptive planning approach.

It is therefore important to regularly monitor changes in the human and built environment such as:

- extent of developed areas potentially exposed to inundation or coastline retreat
- trends in intensification, redevelopment or other changes in existing developed areas
- trends in the community itself – demographic and socio-economic structure, indicators such as health status and employment
- frequency of events that disrupt infrastructure services – road closures, seawall erosion or wave overtopping, stormwater network overloads, costs of maintenance and repair
- loss of natural coastal buffers – rates of loss or retreat of esplanade reserve areas and strips.

A community's vulnerability also needs to be monitored and changes over time identified. This can be measured through changes in land values, reduction in asset values, rates of turnover

of dwellings and insurance cover, and other characteristics of citizens and assets that will increase the likelihood of harm from hazard events.

This information will help in making decisions on community investment in the adaptive pathways planning process.

11.2.3 Monitoring adaptive frameworks for future decisions

Monitoring of changes over time is a necessary part of identifying risk. When areas of high risk are identified, they must be prioritised for planning, including the steps of community engagement and consideration of alternative means of managing change and mitigating risk over time.

The identification of an area of high risk should result in the establishment of a monitoring framework, regardless of whether it triggers an immediate planning exercise and response. A monitoring framework will place the council and affected community in a position where it builds an understanding of emerging changes. That, in turn, will help with planning and help communities identify the timeframe for responses, the nature of the responses and how they need to change over time.

An effective monitoring framework that can be used for adaptive planning over long timeframes will involve the community and may have the following characteristics:

- a general level of agreement on what is important to monitor and how to measure and record it
- justification, in terms of planning needs and cost
- long-term consistency so that any identified decision triggers are embedded in a council monitoring system so changes over time will be signalled, and to ensure a long-term commitment by the council
- a 'champion' or 'public face' associated with the monitoring responsibility
- opportunities for public contribution to the monitoring
- regular reporting (annually, biannually or longer term) with opportunities for comment and review – for example, through becoming part of a council's state of the environment reporting
- monitored changes can then provide the context for the adaptive planning process, which will involve reassessment of response options to gauge whether they still meet the objectives of the plan and may include reviewing the objectives.

11.2.4 Tying monitoring to early signals and triggers (decision points)

Inherent in the adaptive pathways approach is that plans for the future in a changing world will have identified conditions where the responses no longer meet the objectives of the adaptation plan (adaptation threshold). Before this point, at a predefined signal, reassessment of the responses will be necessary to identify whether other actions or transfer to other pathways are required, for example, different investments in protection or the managed relocation or removal of buildings and structures.

The adaptive planning framework will have embedded in it signals and triggers (decision points), which may be based on social, economic or physical circumstances, and may be time related, related to risk exposure or similar circumstances, or tied in with council cycles such as long-term plans or RMA plan reviews whichever is the sooner.

Particular care is needed in identifying trigger points for two reasons. First, if trigger points rely on extremes they may simply reflect natural variability rather than trends due to climate

change, and second, because they may involve an element of physical damage or cost that means they are not consistent with the adaptation plan's objectives. Ideally, trigger points will be identified that result in decisions to move to a new pathway before significant exposure to actual damage or costs occurs, and that are consistent with maintaining or reducing risk. Examples may include an average (reduced from the present) width of an esplanade reserve, a level of cost of maintenance of coastal protection works (hard protection or beach replenishment), or extent and/or frequency of inundation of underground infrastructure (resulting in measurable disruption, rather than actual damage).

An adaptation monitoring framework is required as part of the adaptive planning strategy (step 7). This will be linked to each coastal hazard related plan at the local level as part of the implementation plan (step 8). Relevant physical considerations from section 11.2.1 should be included and the monitoring should apply to the exposed locations specified in the plan. Relevance, long-term consistency and reporting against monitored performance-determined criteria will form the basis of the monitoring framework and programme.

Individual consents also may have trigger conditions, such as distances of mean high water springs from section boundary or dwelling facades or an inundation event frequency. As far as possible, costs and performance of such monitoring should lie with the consent holder. Compliance monitoring should be linked to the councils' monitoring of trigger points in any adaptive plan.

11.2.5 Monitoring effectiveness of policy and plans

Monitoring the efficiency and effectiveness of policy and plans is a statutory RMA requirement for local government and good practice. Monitoring provisions that respond to the changing climate need to continue to allow for the long-term purpose of sustainable management, considering the reasonably foreseeable needs of future generations and the state of knowledge of the actual and potential effects of climate change. An effective monitoring framework, therefore, should consider immediate, medium-term and long-term effectiveness. Where climate change is known to be increasing risks to people and communities under current planning regimes, effectiveness monitoring may start to demonstrate that current policies and other provisions are becoming less relevant than in the past, triggering the need for a review.

A sound information base, including monitoring information, is a fundamental requirement for ongoing planning for adaptation to climate change in the longer term.

11.3 Involving communities in monitoring

Communities, iwi/hapū and stakeholders (including schools and businesses) can contribute to monitoring through projects (eg, coordinated collection and analysis of data by groups in the community), devolved monitoring of specific aspects to iwi/hapū, special interest groups or stakeholders, or local authorities working with industry to monitor changes that affect them, bearing in mind that climate trends will be monitored at a national level. This is set out in table 28.

Table 28: Opportunities to include the community, iwi/hapū and stakeholders in monitoring

Methods	Description	Examples
Community projects	Record and photograph events (eg, king tides initiative or storm 'tide marks) or take measurements to help with more formal methods of collection to gauge effects on community and assets. **Advantages**: Inclusion in monitoring projects creates learning opportunities and may reduce future questions around the science or uncertainty as particular signals and trigger points are approached due to familiarity with the changes. **Disadvantages**: Support and training of volunteers, long-term data storage and/or data bases, ways to collate social and economic data are important and will require further development.	Estuarine monitoring toolkit (NIWA, 2009) Witness King Tides initiative–Auckland (King Tides Initiative, n.d)
Co-management of monitoring by iwi/hapū, special interest groups and other stakeholders	Some groups can undertake parallel and complementary action alongside local authorities.	Coast and estuary care and monitoring activities
Aligned industry monitoring	Individual industries or sectors monitor elements of the environment that are relevant to their activities or consents.	

These approaches involving citizens in monitoring are emerging around New Zealand. The key benefit is the shared understanding on rates of change and progress towards agreed signal and trigger points. They will also help conversations about the appropriateness of trigger points. For example, a community may have decided in 2016 that coastal inundation of a main road twice a year was tolerable. The reality of regular inundation, however, may shift the perspective and alter the trigger point in the future.

The involvement of citizens in monitoring links should contribute to formal and statutory monitoring undertaken by the local authority. Ideally, such programmes are set up in collaboration with local government and information is shared and widely communicated. Establishing the programme and reviewing the findings may also benefit from the involvement of an expert or practitioner.

11.4 Reviewing plans and adaptation pathways

Depending on the nature of the policy, plan or adaptation pathway, regular reviews of early signals and adaptation triggers (decision points) will be needed.

RMA policy and plans need to be assessed and, where necessary, reviewed in terms of appropriateness, efficiency and effectiveness every 10 years (section 32 RMA in combination with the review requirements of section 79). This provides for recognition of changing environmental circumstances and risks that have been identified through the monitoring programme. It also provides for the rolling forward of policy considerations, such as the NZCPS 2010 Policy 24 'at least 100 years', and any new regional or national policy requirements.

Planning involving adaptive pathways, especially for existing development, should already have identified triggers (decision points) at which significant policy or practical modifications to plans or actions will be required by changing to different pathways. These will not be time dependent but will be based on the social and economic effects of physical impacts and the

adaptive capacity of communities (see figure 71 and box 19, Lakes Entrance example), and will emerge through monitoring.

Statutory planning processes, including reviews, have substantial requirements for public consultation and engagement through the formal processes. Such processes are informed by the monitoring information and its evaluation and translation into new policy, plans and pathways. They should also be informed by national guidance and the evolution of practice, such as through case law and the experience of other local authorities.

Planning along adaptive pathways should also provide for emerging research and findings about hazards and risks, development of new tools for managing hazard risk and engagement with the community at key decision points.

12 Tools and resources

12.1 Resources

Ministry for the Environment

- 2016: *Climate Change Projections for New Zealand: Atmosphere projections based on simulations undertaken for the IPCC Fifth Assessment*. Wellington: Ministry for the Environment. Retrieved from www.mfe.govt.nz/publications/climate-change/climate-change-projections-new-zealand.
- 2017: *Preparing for coastal change*. Wellington: Ministry for the Environment. In production (a summary document of this 2016 guidance). www.mfe.govt.nz/publications/climate-change/preparing-coastal-change-companion-coastal-hazards-and-climate-change.

Department of Conservation

- 2010: *New Zealand Coastal Policy Statement*. Wellington: Department of Conservation. Retrieved from www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/new-zealand-coastal-policy-statement-2010/.
- Department of Conservation. 2017. *NZCPS 2010 Guidance Note: Coastal Hazards*. Wellington: Department of Conservation. http://www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/policy-statement-and-guidance/.

Other relevant New Zealand guidance

- Resource Management Act 1991 quality planning resources:
  - *Climate change* (Quality Planning, n.d)
  - *Introduction and the framework and principles for coastal management* (Quality Planning, n.d)
  - *Natural hazards* (Quality Planning, n.d)
  - *Treaty of Waitangi obligations* (Quality Planning, n.d).
- 2005: *Good practice guidelines for working with tangata whenua and Māori organisations: Consolidating our learning*. Landcare Research (Harmsworth, 2005).
- 2011: *Coastal Adaptation to Climate Change: Pathways to Change* (Britton et al, 2011).
- 2012: *Defining coastal hazard zones and setback lines: A guide to good practice* (Ramsay et al, 2012).
- 2013: *Interim guideline to sea boundaries and the Marine and Coastal Area (Takutai Moana) Act 2011* (Land Information New Zealand, 2013).
- 2016: *Standard for New Zealand Vertical Datum 2016* (Land Information New Zealand, 2016).

IPCC Summary and Synthesis Reports: Fifth Assessment Report (2013/14)

- IPCC Working Group I (Physical Science Basis and Projections): Summary for Policymakers (IPCC, 2013b) http://ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf.
- IPCC Working Group II (Impacts, Adaptation, and Vulnerability): Summary for Policymakers (IPCC, 2014b) http://ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf.

- IPCC Climate Change 2014 Synthesis Report, Summary for Policymakers (IPCC, 2014a) http://ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf.

Relevant international adaptation guidance (planning, infrastructure and assets)

- 2012: *Climate Change Adaptation Guidelines in Coastal Management and Planning* (Engineers Australia National Committee on Coastal and Ocean Engineering, 2012).
- 2014: *Highways in the coastal environment: Assessing extreme events* (US Department of Transportation, 2014).
- 2014: *Procedures to evaluate sea level change: Impacts, responses, and adaptation* (US Army Corps of Engineers, 2014).
- 2015: *Sea level rise policy guidance: Interpretative guidelines for addressing sea level rise in local coastal programs and coastal development permits* (California Coastal Commission, 2015).
- 2015: *Guidance for incorporating sea level rise into capital planning in San Francisco: Assessing vulnerability and risk to support adaptation* (City and County of San Francisco Sea Level Rise Committee, 2015).
- 2016: *Characterizing risk in climate change assessments* (National Academies of Sciences, 2016) www.nap.edu/download/23569.
- 2016: CoastAdapt (NCCARF, 2016)
- 2016: *Local authority adaptation strategy development guideline*, Environmental Protection Agency, Ireland (Gray, 2016).
- 2017: *Workbook: How to reduce coastal hazard risk in your community: a step-by-step approach – UNESCO* (Glavovic, in press).

Relevant international community engagement guidance

- 2014: P2 practitioner tools, International Association of Public Participation www.iap2.org/?page=A5.
- 2016: CoastAdapt (NCCARF, 2016).

12.2 Tools and simulation games

- Deltares Decision Simulation Game – www.deltares.nl/en/software/sustainable-delta-game/#1 (see appendix H).
- Urban Impacts Toolbox – impacts of climate change on urban infrastructure and the built environment – www.niwa.co.nz/climate/urban-impacts-toolbox.
- RiskScape – quantitative risk assessment modelling tool developed by NIWA and GNS Science, which covers several natural hazard risks, including coastal storm inundation and tsunami http://riskscape.org.nz/.
- Toolbox for risk based land-use planning for natural hazards – GNS Science www.gns.cri.nz/Home/RBP/Risk-based-planning/A-toolbox.
- Waikato Regional Council Coastal Inundation Tool – interactive online tool for displaying the effect of sea-level rise on coastal-storm inundation www.waikatoregion.govt.nz/coastal-inundation-tool/.
- High Intensity Rainfall Design System (HIRDS) for New Zealand: Version 3 – derives changes in rainfall intensity for a range of higher temperatures due to climate change for locations around New Zealand https://hirds.niwa.co.nz/.

Glossary of abbreviations and terms

Adaptation	Adaptation is considered a response strategy to anticipate and cope with impacts that cannot be (or are not) avoided under different scenarios of climate change (Denton et al, 2014) The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2014c, annex II). Adaptation can be categorised as either: • *incremental* – actions where the central aim is to maintain the essence and integrity of a system or process at a given scale, or, • *transformational* – actions that changes the fundamental attributes of a system in response to climate and its effects. (chapter 9)
Adaptation threshold	The threshold (derived value or performance measure) when agreed objectives, community values, risk exposure, or levels of service are no longer being met or start to fail, requiring an alternative adaptation action or pathway to be in place before this occurs (see figure 70). The adaptation threshold is not tied to a particular time – rather it will be a bracketed time window derived using the scenarios in the DAPP process.
Adaptive capacity	The resources available for adaptation to climate change and variability or other related stresses, as well as the ability of a system to use these resources effectively in the pursuit of adaptation (Brooks and Adger, 2004).
Annual exceedance probability (AEP)	The chance that an event would reach or exceed a given magnitude in any year, expressed as a percentage or decimal (see appendix F)
AR5	IPCC Fifth Assessment Report – covering three working group reports and a synthesis report (the previous assessment report in 2007 was the AR4).
BA	Building Act 2004 (and amendments).
CDEM	Civil defence and emergency management.
CDEMA	Civil Defence and Emergency Management Act 2002.
cGPS	Continuous GPS monitoring of a location (horizontal and vertical).
Climate	Climate in a narrow sense is usually defined as the average weather or, more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands of years. The normal period for averaging climate variables is 30 years (World Meteorological Organization, 2007).

Climate change	Climate change refers to a change in the state of the climate that can be identified (eg, by using statistical tests) by changes or trends in the mean and/or the variability of its properties, and that persists for an extended period, typically decades to centuries. Climate change includes natural internal climate processes or external climate forcings such as variations in solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (adapted from IPCC 2013a, annex III).
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission–concentration–radiative–forcing scenario used, which is in turn based on narrative with assumptions, for example, future socio-economic, technological developments or land-use change that may or may not be realised (adapted from IPCC, 2013a, annex III).
Coastal environment	For a full definition, see Policy 1 of the New Zealand Coastal Policy Statement 2010. Includes not only the coastal marine area but also terrestrial environments and elements connected with the coast, and areas at risk from coastal hazards (including climate change).
Coastal hazard	Subset of *natural hazards* covering tidal or coastal storm inundation, rising sea level, tsunami or meteorological tsunami inundation, coastal erosion (shorelines or cliffs), rise in groundwater levels from storm tides and sea-level rise (plus associated liquefaction), and salinisation of surface fresh waters and groundwater aquifers.
Coastal marine area (CMA)	The foreshore, seabed and coastal water, and the air space above the water. Seaward boundary is the outer limits of the territorial sea. Landward boundary is the line of mean high water springs. Full definition in appendix A (Resource Management Act 1991, section 2).
Community	People who live in a particular geographic location.
Consequences	The outcome of an event that may result from a hazard. It may be expressed quantitatively (eg, monetary value, disruption period, environmental effect), by category (eg, high, medium, low) or descriptively (Ministry of Civil Defence and Emergency Management, pers. comm.).
COP21	Twenty-first annual Conference of the Parties, United Nations Framework Convention on Climate Change, held in Paris in December 2015.
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia.
Dynamic adaptive pathways planning (DAPP)	Applied generically in this guidance; acronym 'dynamic adaptive policy pathways' also used specifically by Haasnoot et al (2013) (see chapter 9 and appendix G).

Deep uncertainty	Represents uncertainty where what is known is only that we do not know ('black swans') or disagreed upon by experts and/or stakeholders with no consensus on what the future might bring. Requires robust decision-making methods and tools to support decision-making and policy analysis (Walker et al, 2013).
District plans	District plans must be prepared by city or district councils to help them carry out their functions under the Resource Management Act 1991.
ENSO	El Niño–Southern Oscillation climate mode that occurs over a two- to five-year cycle, mainly in the Pacific.
Event	Occurrence or change of a particular set of circumstances. Can be one or more occurrences and can have several causes (AS/NZS ISO 31000:2009 Risk management standard).
Exceedances	Number of extreme hazard events that exceed a specified extreme level or magnitude in a given planning timeframe.
Exposure	The presence of people, livelihoods, ecosystems, environmental functions, services and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by natural hazards and climate change (adapted from IPCC, 2014c, annex II). People, property, systems or other assets present in hazard zones or exposed to hazards that are thereby subject to potential losses (Ministry of Civil Defence and Emergency Management, pers. comm.)
Frequency	The number or rate of occurrences of hazard events, usually for a given time period (Ministry of Civil Defence and Emergency Management, pers. comm.).
IAP[2]	International Association for Public Participation – an international organisation advancing the practice of public participation.
IPCC	Intergovernmental Panel on Climate Change – a scientific and intergovernmental body under the auspices of the United Nations.
IPO	Inter-decadal Pacific Oscillation, which is a longer-term ENSO-like mode that occurs over a 20- to 30-year cycle, mainly in the Pacific. The IPO switched to the negative phase around 1999.
Iwi and hapū	Those who are tāngata whenua.
K14	Kopp et al (2014) sea-level rise projections.
LGA	Local Government Act 2002 (and amendments).
LGNZ	Local Government New Zealand (www.lgnz.co.nz/).
Light Detection and Ranging (LiDAR)	A laser scanning system usually mounted on an aircraft with height accuracies down to 0.1 metres.

Likelihood	Likelihood is defined as the probability or chance of a hazard or event occurring. Likelihood is usually described quantitatively as a ratio (eg, 1 in 10), percentage (eg, 10 per cent) or value between 0 and 1 (eg, 0.1), or qualitatively using defined and agreed terms, such as unlikely, virtually certain, about as likely as not.
Land information memorandum (LIM)	Information concerning a land parcel under the Local Government Official Information and Meetings Act 1987 and available on request from territorial local authorities.
MCA	Multi-criteria analysis. Analysis technique for evaluating a range of criteria that are both qualitative and quantitative in nature, reflecting the social, cultural, economic and environmental characteristics of the project outcomes or response options (adapted from New Zealand Asset Management Support – www.nams.org.nz/).
Mean sea level (MSL)	Average (mean) level of the sea relative to a vertical datum over a defined epoch, usually of several years to decades. Baseline MSL for IPCC sea-level rise projections is the average over the period 1986–2005.
Mean sea-level anomaly	Variation of the non-tidal sea level above or below the longer-term MSL on time scales ranging from a month to years due to climate variability. This includes the influence of ENSO and IPO patterns on sea level, winds and sea temperatures, and seasonal effects.
MHWS	Mean high water spring tide. Applies to a high-tide water level as well as the line that marks the landward boundary of the CMA.
Mitigation (of climate change)	A human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014c, annex II).
Mitigation (of natural hazard risks) – or risk reduction	The lessening of the potential adverse impacts of physical hazards (including those that are human induced) through actions that reduce hazard, exposure and vulnerability (IPCC, 2014c, annex II).
Natural hazard	Means any atmospheric, earth or water-related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire or flooding), the action of which adversely affects or may adversely affect human life, property, social and economic activities or other aspects of the environment (Resource Management Act 1991, section 2 (adapted)). Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterised by its timing, location and scale, intensity and probability (Ministry of Civil Defence and Emergency Management, pers. comm.).
NIWA	National Institute of Water and Atmospheric Research
NPS	National policy statement (see Resource Management Act 1991, sections 45–55).

NZCPS 2010	New Zealand Coastal Policy Statement 2010. A mandatory national policy statement under the Resource Management Act 1991. Administered by the Department of Conservation.
Path dependency	The generic situation where decisions, events or outcomes at one point in time constrain adaptation, mitigation or other actions or options at a later point in time (IPCC, 2014c, annex II).
Parliamentary Commissioner for the Environment	Parliamentary Commissioner for the Environment is an independent adviser to the Government on environmental issues. The Commissioner investigates emerging environmental issues and concerns from the public.
Percentile	A percentile is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations or projections fall. The 50th percentile is the median. Used to measure the spread of numerous sea-level rise projection simulations from various models and inputs for a particular representative concentration pathway.
Perigean spring tide	A tide that peaks in clusters about every seven months when the moon's perigee (its closest point to Earth during its 28-day elliptical orbit) coincides with a spring tide (when the Earth, sun and moon are nearly aligned every two weeks).
Project information memorandum (PIM)	A PIM is a report issued by a council on request under section 31 of the Building Act 2004 in relation to a building project.
Probability	Chance or likelihood that an event will happen or hazard magnitude be exceeded.
Projections	Used in two senses in the climate change literature. In general usage, a projection can be regarded as any description of the future and the pathway leading to it (ie, not a 'prediction'). A more specific interpretation, however, has been attached to the term 'climate projection' or 'sea-level rise projection' by the IPCC when referring to model-derived estimates of future climate.
Representative concentration pathway (RCP)	Four scenarios of future radiative forcings from greenhouse gases.
Real options analysis (ROA)	Allows economic analysis of future option value and economic benefit of deferring investment.
Regional councils	Regional councils primarily manage resources like the air, water, soils and the coastal marine area, along with natural hazards, civil defence, regional land transport and harbour navigation and safety. New Zealand has 11 regional councils.
Regional plans	Regional plans can be prepared by regional councils if they want to use them to help manage the resources they are responsible for.

Regional policy statement (RPS)	Regional policy statements must be prepared by all regional councils and help set the direction for the coordinated management of all resources across the region.
Residual risk	The risk that remains after risk treatment or management has been applied to reduce the potential *consequences*. (Ministry of Civil Defence and Emergency Management, pers. comm.)
Risk	Effect of uncertainty on objectives (AS/NZS ISO 31000:2009, Risk management standard). Risk is often expressed in terms of a combination of consequences of an *event* (including changes in circumstances) and the associated likelihood of occurrence.
Risk assessment	The overall qualitative and/or quantitative process of *risk* identification, *risk* analysis and *risk* evaluation (AS/NZS ISO 31000:2009, Risk management standard).
Risk management	Plans, actions or policies to reduce the *likelihood* and/or *consequences* of risks or to respond to *consequences* (ISO 31000:2009, Risk management standard).
RMA	The Resource Management Act 1991 and subsequent amendments is New Zealand's main piece of environmental legislation providing the framework for managing the effects of activities on the environment.
Scenario	Plausible descriptions of how the future might unfold in terms of interacting factors, including human behaviour, policy choices, land-use change, global population trends, economic conditions, technological advances, international competition and cooperation (Moss et al, 2010).
Signals	Derived indicator values, monitoring changes in physical, social, cultural, economic, and risk attributes, which provide early warning to signal that a *trigger (*decision point) is approaching in the near to medium term and should prompt thinking and initial engagement processes on the next steps or any changes to the trigger (see figure 70).
Significant wave height	A measure of the highest one-third (33 per cent) of waves over a measurement or modelled period – relates to the height of waves that an observer may estimate.
SLR	Sea-level rise.
Spatial planning	Planning that is undertaken to influence the future spatial distribution of land-use activities within a defined area.
Stakeholder	Those who have an interest in a geographic area or issue, for example, an asset, utility or a value that is at stake.

Static or 'bathtub' inundation model	Hydrodynamic modelling of coastal inundation that does not include the *dynamic* or transient effects of waves or storm tide flooding of land. Essentially transfers the coastal water level inland until that land elevation is reached.
Storm surge	Temporary increase in sea level induced by winds and barometric pressure associated with weather systems.
Storm tide	Combination of MSL, high tide, storm surge and MSL anomaly, but excludes wave setup and runup.
Territorial authorities	Territorial authorities are city and district councils primarily responsible for managing the effects of activities on land.
Trigger (decision point)	A derived indicator value(s), which when reached, provides sufficient lead time to cover community engagement, consenting, construction and funding arrangements, to ensure a new pathway or adaptation action can be implemented before the adaptation threshold is reached (see figure 70). The trigger is not tied to a particular time – rather it will be a bracketed time window derived using the scenarios in the DAPP process.
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour (IPCC, 2014c, annex II).
Uncertainty (risk)	Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its *consequences* or *likelihood* (AS/NZS ISO 31000:2009, Risk management standard)
UNFCCC	United Nations Framework Convention on Climate Change. Came into existence in March 1994 following the Rio Earth Summit in 1992. To date, 197 countries have ratified the Convention and are called Parties to the Convention. Preventing 'dangerous' human interference with the climate system is the ultimate aim of the UNFCCC.
Unitary authorities	Unitary authorities carry out the roles of both regional and district councils. There are currently six, for example, Auckland Council, Tasman District Council and others.
Vulnerability	The predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including exposure, sensitivity or susceptibility to harm or damage, and lack of capacity to cope and adapt (adaptive capacity) (adapted from IPCC, 2014c, annex II).

Vulnerability assessment (VA)	Process of identifying, quantifying and prioritising (or ranking) the *vulnerabilities* in a system, environment or community, conducted across the political, social, economic and environmental fields, as well as those highlighted by hazard threats to community and private assets. Vulnerability assessment has many things in common with *risk assessment*, but is broader by including indirect and intangible consequences and assessing *adaptive capacity*.
Water table	The 'surface' of the subsurface sediments that are saturated with groundwater in a given vicinity. Typically measured as the elevation that water rises to in a well screened in shallow groundwater.
Wave overtopping	Occurs when the wave runup exceeds the crest elevation of the beach and flows over the top ('overtops') of the dune or seawall.
Wave runup	The maximum vertical extent of sporadic wave 'up rush' or flowing water ('green water') on a beach or structure above the still water or storm tide level, and thus constitutes only a short-term upper-bound fluctuation in water level compared with wave setup.
Wave setup	The increase in mean still water sea level at the coast resulting from the release of wave energy in the surf zone as waves break.

References

Ackerley D, Bell RG, Mullan AB, McMillan H. 2013. Estimation of regional departures from global-average sea-level rise around New Zealand from AOGCM simulations. *Weather & Climate* 33: 2–22.

Allis MJ, Stephens S, Ramsay D, Gorman R, Bell R. 2015. *The Coastal Calculator: A user-friendly tool for estimating coastal storm-driven water-levels*. Proceedings of Australasian Coasts & Ports Conference 2015: 7. 15–18 September 2015, Auckland, New Zealand.

Atlas Communications & Media Ltd. 2011. Project Twin Streams case study: Largescale property purchase without recourse to compulsory purchase. Prepared for the Ministry for the Environment on behalf of Waitakere City Council, Ministry for the Environment, Publication No. CR 108. Retrieved from: www.mfe.govt.nz/publications/climate-change/project-twin-streams-case-study-large-scale-property-purchase-without.

Auckland Council. 2016. The proposed Auckland Unitary Plan – Decisions Version (19 August 2016). www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/plansstrategies/unitaryplan/Pages/aucklandcouncildecisionversion.aspx.

Baker RF, Watkins M. 1991. *Guidance notes for the determination of mean high water mark for land title surveys*. Wellington: Professional Development Committee of the New Zealand Institute of Surveyors. Retrieved from http://docs.niwa.co.nz/library/public/Baker1991.pdf (November 2016).

Bamber JL, Aspinall WP. 2013. An expert judgement assessment of future sea level rise from the ice sheets. *Nature Climate Change* 3(4): 424–427. Retrieved from www.nature.com/nclimate/journal/v3/n4/abs/nclimate1778.html#supplementary-information.

Bamber JL, Aspinall WP, Cooke RM. 2016. A commentary on "how to interpret expert judgment assessments of twenty-first century sea-level rise" by Hylke de Vries and Roderik SW van de Wal. *Climatic Change* 137(3): 321–328. Retrieved from http://dx.doi.org/10.1007/s10584-016-1672-7.

Bamber JL, Riva REM, Vermeersen BLA, LeBrocq AM. 2009. Reassessment of the potential sea-level rise from a collapse of the West Antarctic Ice Sheet. *Science* 324(5929): 901–903. http://dx.doi.org/10.1126/science.1169335.

Barisky T. 2015. *A public engagement toolkit for sea level rise*. Prepared for the Sustainability Group, City of Vancouver. Vancouver: City of Vancouver. Retrieved from https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2015%20Project%20Reports/A%20Public%20Engagement%20Toolkit%20for%20Sea%20Level%20Rise%20-%20GC%20Scholars%202015.pdf.

Barlow PM. 2003. Ground water in freshwater-saltwater environments of the Atlantic Coast. *US Geological Survey Circular* 1262: 113.

Barnett J, Graham S, Mortreux C, Fincher R, Waters E, Hurlimann A. 2014. A local coastal adaptation pathway. *Nature Climate Change* 4(12): 1103–1108. Retrieved from http://dx.doi.org/10.1038/nclimate2383.

Barnett J, Tschakert P, Head L, Adger WN. 2016. A science of loss. *Nature Climate Change* 6: 976–978.

Barnett MAF. 1938. *The cyclonic storms in Northern New Zealand. Meteorological Office Note 22*. Wellington: Meteorological Office.

Beavan RJ, Litchfield NJ. 2012. *Vertical land movement around the New Zealand coastline: Implications for sea-level rise*. Lower Hutt: GNS Science. Retrieved from www.gns.cri.nz/static/pubs/2012/SR%202012-029.pdf.

Becker JS, Stewart C, Coomer M, Hume T, Blackett P, Davies A. 2007. *Managing our coast: The tabulated results of two community surveys undertaken at Tairua and Waihi Beach*. Lower Hutt: Institute of

Geological and Nuclear Science. Retrieved from www.massey.ac.nz/massey/fms/Colleges/College%20of%20Humanities%20and%20Social%20Sciences/Psychology/Disasters/pubs/GNS/2007/SR%202007-028%20Waikato%20Coastal%20Survey%20of%20Waihi%20and%20Tairua.pdf?2D270087F220B02096617E9EA3B9CAAF.

Bell RG. 2010. Tidal exceedances, storm tides and the effect of sea-level rise. In: *Proceedings of the 17th Congress of the Asia and Pacific division of the IAHR*. Auckland: 10.

Bell RG, Paulik R, Wadhwa S. 2015. *National and regional risk exposure in low-lying coastal areas: areal extent, population, buildings and infrastructure*. Report prepared for the Parliamentary Commissioner for the Environment by NIWA. Wellington: Parliamentary Commissioner for the Environment. Retrieved from www.pce.parliament.nz/media/1384/national-and-regional-risk-exposure-in-low-lying-coastal-areas-niwa-2015.pdf.

Berg K, Pettersson R. 2004. *Analysis of the National Coastal Survey 2003: Wellington region results*. Wellington: Greater Wellington Regional Council. Retrieved from www.gw.govt.nz/assets/council-publications/Environment%20Management_20040420_163833.pdf.

Berkes F, Folke C, Colding J. 1998. Ecological practices and social mechanisms. In: F Berkes, C Folke, J Colding (eds) *Linking Social and Ecological Systems: Management practices and social mechanisms for building resilience*. Cambridge: Cambridge University Press.

Blackett P, Hume T, Dahm J. 2010a. Exploring the social context of coastal erosion management in New Zealand: What factors drive environmental outcome. *The Australasian Journal of Disaster and Trauma Studies* 2010-1: 10.

Blackett P, Smith E, Rouse H, Hume T, Rickard D, Hume A, Bell R, Ramsey D, Dahm J, Wishart P, Singleton P, Pickett V. 2010b. *How can we engage with coastal communities over adaptation to climate change? A case study in Whitianga on the Coromandel Peninsula*. Presentation to New Zealand Planning Institute Conference: Planning Pathways to the Future, Christchurch Convention Centre 20–23 April 2010.

Boston Research Advisory Group. 2016a. *Climate change and sea level rise projections for Boston*. The Boston Research Advisory Group Report, Climate Ready Boston Project. https://www.boston.gov/environment-and-energy/climate-ready-boston.

Boston Research Advisory Group. 2016b. *Climate Ready Boston*. Retrieved from https://www.boston.gov/environment-and-energy/climate-ready-boston (November 2016).

Brenstrum E. 1998. The New Zealand Weather Book. Nelson: Craig Potton Publishing: Nelson.

Britton R, Dahm J, Rouse H, Hume T, Bell R, Blackett P. 2011. *Coastal adaptation to climate change: Pathways to change*. Wellington: NIWA. Retrieved from www.niwa.co.nz/sites/default/files/pathways_to_change_nov2011.pdf.

Brooks N, Adger WN. 2004. Assessing and enhancing adaptive capacity. In: B Lim, I Burton, E Malone, S Huq (eds) Adaptation policy frameworks for climate change: Developing strategies, policies and measures: 165–181. Cambridge: Cambridge University Press. Retrieved from: www.preventionweb.net/publications/view/7995.

Brown Gaddis EJ, Harp Falk H, Ginger C, Voinov A. 2010. Effectiveness of a participatory modeling effort to identify and advance community water resource goals in St. Albans, Vermont. *Environmental Modelling & Software* 25(11): 1428–1438. Retrieved from http://dx.doi.org/10.1016/j.envsoft.2009.06.004.

Bruun P. 1962. Sea-level rise as a cause of shore erosion. *Journal Waterways and Harbors Division*, ASCE, 88: 117–130.

Bryan KR, Foster R, MacDonald I. 2013. Beach rotation at two adjacent headland-enclosed beaches. *Journal of Coastal Research, Special Issue 65*: 2095–2100.

Bryson JM, Quick KS, Slotterback CS, Crosby BC. 2013. Designing public participation processes. *Public Administration Review* 73(1): 23–34.

Buchanan MK, Kopp RE, Oppenheimer M, Tebaldi C. 2016. Allowances for evolving coastal flood risk under uncertain local sea-level rise. *Climatic Change* 137(3): 347–362.

Burkett VR, Suarez AG, Bindi M, Conde C, Mukerji R, Prather MJ, Clair ALS, Yohe GW. 2014. Point of departure. In: CB Field, VR Barros, DJ Dokken et al (eds) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Burton I. 2009. Climate change and the adaptation deficit. In: LE Schipper, I Burton (eds) *The Earthscan Reader on Adaptation to Climate Change*, 1st Edition: 89–95. London: Earthscan.

California Coastal Commission. 2015. *Sea level rise policy guidance: Interpretative guidelines for addressing sea level rise in local coastal programs and coastal development permits*. San Francisco: California Coastal Commission. Retrieved from www.coastal.ca.gov/climate/slrguidance.html.

Center for Science in the Earth System. 2007. *Preparing for climate change: A guidebook for local, regional, and state governments*. Washington: University of Washington. Retrieved from http://icleiusa.org/wp-content/uploads/2015/08/PreparingForClimateChange_Sept2007.pdf.

Chambers DP, Cazenave A, Champollion N, Dieng H, Llovel W, Forsberg R, von Schuckmann K, Wada Y. 2016. Evaluation of the global mean sea level budget between 1993 and 2014. *Surveys in Geophysics: 1–19*. Retrieved from http://dx.doi.org/10.1007/s10712-016-9381-3.

Chambers R. 2002. *Participatory workshops: A source of 21 sets of ideas and activities*. London: Earthscan: 236. ISBN: 1-85383-863-2.

Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A, Merrifield MA, Milne GA, Nerem RS, Nunn PD, Payne AJ, Pfeffer WT, Stammer D, Unnikrishnan AS. 2013a. Sea level change. In: TF Stocker, D Qin, G-K Plattner et al (eds) *Climate Change 2013: The physical science basis.* Cambridge: Cambridge University Press.

Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A, Merrifield MA, Milne GA, Nerem RS, Nunn PD, Payne AJ, Pfeffer WT, Stammer D, Unnikrishnan AS. 2013b. Sea-level rise by 2100. *Science* 342(6165): 1445–1445. Retrieved from http://dx.doi.org/10.1126/science.342.6165.1445-a.

Church JA, McInnes KL, Monselesan D, O'Grady J. 2016. *Sea-level rise and allowances for coastal councils around Australia – Guidance material.* Report by CSIRO–Oceans and Atmosphere to the National Climate Change Adaptation Research Facility (NCCARF): 64. Retrieved from https://coastadapt.com.au/sites/default/files/factsheets/DSG1_1_CSIRO_guidelines_SLR.pdf.

Church JA, White NJ. 2011. Sea-Level Rise from the Late 19th to the Early 21st Century. *Surveys in Geophysics* 32(4): 585–602. Retrieved from http://dx.doi.org/10.1007/s10712-011-9119-1.

Church JA, Woodworth PL, Aarup T, Wilson WS (eds). 2010. *Understanding sea-level rise and variability*. Chichester: Wiley-Blackwell.

Cinderby S. 1999. Geographic information systems (GIS) for participation: The future of environmental GIS? *International Journal of Environment and Pollution* 11(3): 304–315. Retrieved from www.scopus.com/inward/record.url?eid=2-s2.0-0032679804&partnerID=40.

Cinderby S. 2010. How to reach the 'hard-to-reach': The development of Participatory Geographic Information Systems (P-GIS) for inclusive urban design in UK cities. *Area* 42(2): 239–251. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4762.2009.00912.x/abstract.

Cinderby S, Forrester J. 2005. Facilitating the local governance of air pollution using GIS for participation. *Applied Geography* 25(2): 143–158. Retrieved from www.scopus.com/inward/record.url?eid=2-s2.0-19144362389&partnerID=40.

Cinderby S, Snell C, Forrester J. 2008. Participatory GIS and its application in governance: the example of air quality and the implications for noise pollution. *Local Environment* 13(4): 309–320.

City and County of San Francisco Sea Level Rise Committee. 2015. *Guidance for incorporating sea level rise into capital planning in San Francisco: Assessing vulnerability and risk to support adaptation*. San Francisco: The City and County of San Francisco. Retrieved from http://onesanfrancisco.org/sea-level-rise-guidance.

Collins M, Knutti R, Arblaster J, Dufresne J-L, Fichefet T, Friedlingstein P, Gao X, Gutowski WJ, Johns T, Krinner G, Shongwe M, Tebaldi C, Weaver AJ, Wehner M. 2013. Long-term climate change: projections, commitments and irreversibility. In: TF Stocker, D Qin, G-K Plattner et al (eds) *Climate change 2013: The physical science basis*. Cambridge: Cambridge University Press.

Clark PU, Church JA, Gregory JM, Payne AJ. 2015. Recent Progress in Understanding and Projecting Regional and Global Mean Sea Level Change. *Current Climate Change Reports* 1(4): 224–246. Retrieved from http://dx.doi.org/10.1007/s40641-015-0024-4.

Clark PU, Shakun JD, Marcott SA, Mix AC, Eby M, Kulp S, Levermann A, Milne GA, Pfister PL, Santer BD, Schrag DP, Solomon S, Stocker TF, Strauss BH, Weaver AJ, Winkelmann R, Archer D, Bard E, Goldner A, Lambeck K, Pierrehumbert RT, Plattner G-K. 2016. Consequences of twenty-first-century policy for multi-millennial climate and sea-level change. *Nature Climate Change* 6(4): 360–369. Retrieved from http://www.nature.com/nclimate/journal/v6/n4/full/nclimate2923.html.

Cote M, Nightingale AJ. 2012. Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4): 475–489. Retrieved from http://dx.doi.org/10.1177/0309132511425708.

Coastal Hazard Committee. 2016. *Clifton to Tangoio Coastal Hazards Strategy 2120 – Strategy Development*. Retrieved from www.hbcoast.co.nz/strategy-development/.

Cowell PJ, Thom BG, Jones RA, Everts CH, Simanovic D. 2006. Management of uncertainty in predicting climate-change impacts on beaches. *Journal of Coastal Research* 22(1): 232–245.

Cox JC, Machemehl J. 1986. Overload bore propagation due to an overtopping wave. *Journal of Waterway Port Coastal and Ocean Engineering-ASCE* 112(1): 161–163.

CSIRO. 2016. Combined TOPEX/Poseidon, Jason-1 and Jason-2/OSTM sea level fields. www.cmar.csiro.au/sealevel/sl_data_cmar.html, accessed August 2016.

Dangendorf S, Marcos M, Müller A, Zorita E, Riva R, Berk K, Jensen J. 2015. Detecting anthropogenic footprints in sea level rise. *Nature Communications* 6:7849. Retrieved from http://dx.doi.org/10.1038/ncomms8849.

Dangendorf S, Rybski D, Mudersbach C, Müller A, Kaufmann E, Zorita E, Jensen J. 2014. Evidence for long-term memory in sea level. *Geophysical Research Letters* 41(15): 5530–5537. Retrieved from http://dx.doi.org/10.1002/2014GL060538.

Davies K, Fisher K, Dickson M, Thrush S, LeHeron R. 2015. Improving ecosystem service frameworks to address wicked problems. *Ecology and Society* 20(2): 37. Retrieved from http://dx.doi.org/10.5751/ES-07581-200237.

de Vries H, van de Wal RSW. 2015. How to interpret expert judgment assessments of 21st century sea-level rise. *Climatic Change* 130(2): 87–100. Retrieved from http://dx.doi.org/10.1007/s10584-015-1346-x.

DeConto RM, Pollard D. 2016. Contribution of Antarctica to past and future sea-level rise. *Nature* 531(7596): 591–597. Retrieved from http:dx.doi.org/10.1038/nature17145.

Denton F, Wilbanks TJ, Abeysinghe AC, Burton I, Gao Q, Lemos MC, Masui T, O'Brien KL, Warner K. 2014. Climate-resilient pathways: Adaptation, mitigation, and sustainable development. In: CB Field, VR Barros, DJ Dokken et al (eds) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Retrieved from http://ipcc.ch/report/ar5/wg2/.

Denys P, Beavan RJ, Hannah J, Pearson CF. In press. Sea level rise in New Zealand: The implication of vertical land motion on tide gauge records. *Journal of Geophysical Research – Solid Earth.*

Department for Environment, Food and Rural Affairs. 2012. *UK Climate Change Risk Assessment: Government Report*. London: Department for Environment, Food and Rural Affairs. Retrieved from www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report.

Department of Climate Change and Energy Efficiency. 2011. *Climate change risks to coastal buildings and infrastructure: A Supplement to the First Pass National Assessment*. Canberra: Department of Climate Change and Energy Efficiency. Retrieved from www.environment.gov.au/climate-change/adaptation/publications/climate-change-risks-coastal-buildings.

Department of Conservation. 2010. *New Zealand Coastal Policy Statement 2010*. Wellington: Department of Conservation. Retrieved from www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/new-zealand-coastal-policy-statement-2010/.

Department of Conservation. 2017. *NZCPS 2010 Guidance Note: Coastal Hazards*. Wellington: Department of Conservation.

Dessai S, Hulme M, Lempert R, Pielke R. 2009. Climate prediction: A limit to adaptation? In: WN Adger, I Lorenzoni, KL O'Brien (eds) *Adapting to Climate Change*. Cambridge: Cambridge University Press, Cambridge.

Dickson ME, Walkden MJ, Hall JW. 2007. Systemic impacts of climate change on an eroding coastal region over the 21st century. *Climatic Change* 84: 141–166.

Douglas BC. 2001. Sea level change in the era of the recording tide gauge. In: BC Douglas, MS Kearney, PL Stephen (eds) *International Geophysics*. San Diego: Academic Press. Retrieved from http://dx.doi.org/10.1016/S0074-6142(01)80006-1.

Dovers SR, Hezri AA. 2010. Institutions and policy processes: the means to the ends of adaptation. *Wiley Interdisciplinary Reviews: Climate Change* 1: 212–231. Retrieved from http://wires.wiley.com/WileyCDA/WiresArticle/wisId-WCC29.html.

Dune Restoration Trust of New Zealand. 2016. *Coast Care Groups Map*. Retrieved from www.dunestrust.org.nz/coastcare-groups/coastcare-groups-map (6 November 2016).

Earlie CS, Young AP, Masselink G, Russell PE. 2015. Coastal cliff ground motions and response to extreme storm waves. *Geophysical Research Letters* 42(3): 847–854.

Engineers Australia National Committee on Coastal and Ocean Engineering. 2012. *Climate Change Adaptation Guidelines in Coastal Management and Planning*. Barton ACT: Engineers Australia. Retrieved from www.engineersaustralia.org.au/coastal-ocean-engineering/publications.

Evans L, Milfont TL, Lawrence J. 2014. Considering local adaptation increases willingness to mitigate. *Global Environmental Change* 25: 69–75. http://dx.doi.org/10.1016/j.gloenvcha.2013.12.013.

Fasullo JT, Nerem RS, Hamlington B. 2016. Is the detection of accelerated sea level rise imminent? *Scientific Reports* 6: 31245. Retrieved from http://dx.doi.org/10.1038/srep31245.

Feldmann J, Levermann A. 2015. Collapse of the West Antarctic Ice Sheet after local destabilization of the Amundsen Basin. *Proceedings of the National Academy of Sciences* 112(46): 14191–14196. http://dx.doi.org/10.1073/pnas.1512482112.

FEMA. 2005. *Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States, Section D.4.5: Wave Setup, Runup, and Overtopping*. Oakland: FEMA. Retrieved from www.fema.gov/media-library-data/1389126436477-5bd6d5959718cf3f5a4b6e919f0c3b42/Guidelines%20for%20Coastal%20Flood%20Hazard%20Analysis%20and%20Mapping%20for%20the%20Pacific%20Coast%20of%20the%20United%20States%20(Jan%202005).pdf.

Flick U. 2009. *Introduction to quantitative research*, 4th Edition. London: Sage Publications Ltd. 504 p. ISBN 978-84787-323-1.

Folke C, Hahn T, Olsson P, Norberg J. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* 30: 441–473. Retrieved from http://dx.doi.org/10.1146/annurev.energy.30.050504.144511.

Forbes DL, Orford JD, Carter RWG, Shaw J, Jennings SC. 1995. Morphodynamic evolution, self-organization, and instability of coarse-clastic barriers on paraglacial coasts. *Marine Geology* 126(1-4): 63–85. doi: 10.1016/0025-3227(95)00066-8.

Ford JD, Stephenson E, Cunsolo Willox A, Edge V, Farahbakhsh K, Furgal C, Harper S, Chatwood S, Mauro I, Pearce T, Austin S, Bunce A, Bussalleu A, Diaz J, Finner K, Gordon A, Huet C, Kitching K, Lardeau M, McDowell G, McDonald E, Nakoneczny L, Sherman M. 2016. Community-based adaptation research in the Canadian Arctic. *Wiley Interdisciplinary Reviews: Climate Change* 7(2): 175–191. doi: 10.1002/wcc.376.

Forester J. 2009. *Dealing with differences: Dramas of mediating public disputes*. Oxford: Oxford University Press: 240. ISBN: 9780195385908.

Forester J, Theckethil RK. 2009. Rethinking risk management policies: From participation to processes of dialogue, debate and negotiation. In: UF Paleo (ed.) *Building safer communities: Risk governance, spatial planning and responses to natural hazards*, Volume 58, NATO Science for Peace and Security: 34–43. Amsterdam: IOS Press.

Frame B, Reisinger A. 2016. Exploring options for New Zealand under different global climates. Synthesis Report RA5. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100. MBIE Contract C01X1225.

Fretwell P, Pritchard HD, Vaughan DG, Bamber JL, Barrand NE, Bell R, … Zirizzotti A. 2013. Bedmap2: improved ice bed, surface and thickness datasets for Antarctica. *The Cryosphere* 7: 375–393. doi: 10.5194/tc-7-375-2013.

Fuss S, Canadell JG, Peters GP, Tavoni M, Andrew RM, Ciais P, Jackson RB, Jones CD, Kraxner F, Nakicenovic N, Le Quere C, Raupach MR, Sharifi A, Smith P, Yamagata Y. 2014. Betting on negative emissions. *Nature Climate Change* 4(10): 850–853. Retrieved from http://dx.doi.org/10.1038/nclimate2392.

Gehrels WR, Hayward BW, Newnham RM, Southall KE. 2008. A 20th century acceleration of sea-level rise in New Zealand. *Geophysical Research Letters* 35(2): L02717. Retrieved from http://dx.doi.org/10.1029/2007GL032632.

Gibb JG. 1998. *Assessment of coastal hazard zones for Tolaga Bay and Anaura Bay, Gisborne District, by GIS computer model*. Prepared for Gisborne District Council by Coastal Management Consultancy Ltd. Gisborne: Gisborne District Council.

Gibbs MT. 2015. Guiding principles for infrastructure climate change risk and adaptation studies. *Civil Engineering and Environmental Systems* 32(3): 206–215.

Glavovic BC (ed.). In press. *Workbook: How to reduce coastal hazard risk in your community: A step-by-step approach*. Intergovernmental Oceanographic Commission (IOC) Technical Report Series No. 127. Paris: UNESCO.

Glavovic BC. 2015. On the frontline in the Anthropocene: Adapting to climate change through deliberative coastal governance. In: Glavovic, BC, Kelly, M, Kay, R, Travers A. (Eds.) *Climate Change and the Coast: Building Resilient* Communities: 51-100. Boca Raton: CRC Press / Taylor & Francis. https://www.taylorfrancis.com/books/e/9781482288582.

Glavovic BC, Smith GP (eds). 2014. *Adapting to climate change: Lessons from natural hazards planning*. Springer. Retrieved from www.bookmetrix.com/detail/book/43e77567-8a84-4a98-befa-f85ce8e76979#citations.

Global Carbon Project. 2016. Annual update on the global carbon budget and trends. www.globalcarbonproject.org/carbonbudget/index.htm (accessed October 2016).

Golledge NR, Kowalewski DE, Naish TR, Levy RH, Fogwill CJ, Gasson EGW. 2015. The multi-millennial Antarctic commitment to future sea-level rise. *Nature* 526(7573): 421–425. Retrieved from: http://dx.doi.org/10.1038/nature15706.

Goodhue N, Allis M, Stephens SA, Gorman RM, Robinson B. 2015. *Bay of Plenty storm tide and wave hazard*. Prepared for Bay of Plenty Regional Council by NIWA. Whakatane: Bay of Plenty Regional Council.

Goodhue N, Rouse H, Ramsay D, Bell R, Hume T, Hicks M. 2012. *Coastal Adaptation to Climate Change: Mapping a New Zealand Coastal Sensitivity Index*. Prepared for the Ministry of Business, Innovation and Employment by NIWA. Hamilton: NIWA. Retrieved from www.niwa.co.nz/sites/niwa.co.nz/files/ham2013-011_-_nz_coastal_sensitivity_index.pdf.

Gorman RM. 2016. Projected changes in New Zealand's wave climate. New Zealand Coastal Society 24th Annual Conference. Dunedin, 16–18 November 2016. Abstracts p. 53.

Gorman RM, Bell RG. 2011. What's happening to New Zealand's wave climate? Presentation at the New Zealand Coastal Society New Zealand Coastal Society 19th Annual Conference, Nelson, 6–9 November 2011. Abstracts p. 25.

Gray, S. 2016. *Local authority adaptation strategy development guideline*. Research Report 164, prepared by University College Cork for Environmental Protection Agency (Ireland): 31. Retrieved from www.epa.ie/pubs/reports/research/climate/EPA_Research_Report164.pdf.

Greater Wellington Regional Council. 2015a. *Flood protection: Option flexibility and its value Hutt River City Centre Upgrade River Corridor Options Report*. Prepared for Greater Wellington Regional Council by Infometrics & PS Consulting. Wellington: Greater Wellington Regional Council.

Greater Wellington Regional Council. 2015b. *Hutt River City Centre Upgrade Project: River Corridor Options.* Wellington: Greater Wellington Regional Council. Retrieved from www.gw.govt.nz/assets/floodprotection/Hutt-River-FMGM/HuttRiverCityCentre-RiverCorridorOptionReport.pdf.

Haasnoot M, Kwakkel JH, Walker WE, ter Maat J. 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change* 23(2): 485–498. Retrieved from http://dx.doi.org/10.1016/j.gloenvcha.2012.12.006.

Haasnoot M, Middelkoop H, Offermans A, van Beek E, van Deursen WPA. 2012. Exploring pathways for sustainable water management in river deltas in a changing environment. *Climatic Change* 115(3): 795–819. doi: 10.1007/s10584-012-0444-2.

Haasnoot M, Middelkoop H, van Beek E, van Deursen WPA. 2011. A method to develop sustainable water management strategies for an uncertain future. *Sustainable Development* 19(6): 369–381. Retrieved from http://dx.doi.org/10.1002/sd.438.

Haasnoot M, Schellekens J, Beersma H, Middelkoop J, Kwadijk TCJ. 2015. Transient scenarios for robust climate change adaptation illustrated for water management in the Netherlands. *Environmental Research Letters* 10(10): 105008. doi: 10.1088/1748-9326/10/10/105008.

Hallegatte S, Shah A, Lempert R, Brown C, Gill S. 2012. *Investment Decision Making under Deep Uncertainty – Application to Climate Change*. Washington DC: World Bank. Retrieved from http://dx.doi.org/10.1596/1813-9450-6193.

Hamlington BD, Cheon SH, Thompson PR, Merrifield MA, Nerem RS, Leben RR, Kim KY. 2016a. An ongoing shift in Pacific Ocean sea level. *Journal of Geophysical Research: Oceans* 121(7): 5084–5097. Retrieved from http://dx.doi.org/10.1002/2016JC011815.

Hamlington BD, Thompson P, Hammond WC, Blewitt G, Ray RD. 2016b. Assessing the impact of vertical land motion on twentieth century global mean sea level estimates. *Journal of Geophysical Research: Oceans* 121(7): 4980–4993. Retrieved from http://dx.doi.org/10.1002/2016JC011747.

Han W, Meehl GA, Stammer D, Hu A, Hamlington B, Kenigson J, Palanisamy H, Thompson P. 2016. Spatial patterns of sea level variability associated with natural internal climate modes. *Surveys in Geophysics*. Retrieved from http://dx.doi.org/10.1007/s10712-016-9386-y (November 2016).

Handmer J. 2008. Risk creation, bearing and sharing on Australian floodplains. *International Journal of Water Resources Development* 24(4): 527–540. Retrieved from http://dx.doi.org/10.1080/07900620801921439.

Hannah J. 2004. An updated analysis of long-term sea level change in New Zealand. *Geophysical Research Letters* 31(3): L03307. Retrieved from http://dx.doi.org/10.1029/2003GL019166.

Hannah J. 2016. *Updated historic sea-level rise trends in New Zealand up to 2015: MfE Guidance Manual*. Report to NIWA by Vision New Zealand Ltd. (Note: main content largely replicated in chapter 5 or appendix E.)

Hannah J, Bell RG. 2012. Regional sea level trends in New Zealand. *Journal of Geophysical Research: Oceans* 117(C1): C01004. Retrieved from http://dx.doi.org/10.1029/2011JC007591.

Harmsworth G. 2005. *Good practice guidelines for working with tangata whenua and Māori organisations: Consolidating our learning*. Palmerston North: Landcare Research. Retrieved from www.landcareresearch.co.nz/publications/researchpubs/harmsworth_good_practice_tanagata_whenua.pdf.

Harmsworth G, Awatere S, Robb M. 2015. *Policy Brief: Māori values and perspectives to inform collaborative processes and planning for freshwater management*. Palmerston North: Landcare Research. Retrieved from https://www.landcareresearch.co.nz/__data/assets/pdf_file/0009/111042/PB_14_Maori_Values_Perspectives.pdf.

Harris R. 2004. The coastal and marine environment. In: Harris R (ed.) *Handbook of Environmental Law*. Royal Forest and Bird Protection Society of New Zealand: Wellington. pp 235–267.

Harteveld C. 2012. *Making sense of virtual risks: A quasi-experimental Investigation into game-based training, policy, organisation, law & gaming*. Delft University of Technology, Delft, The Netherlands: 409. doi: 10.4233/uuid:c3d38ad9-88cb-403c-b69e-ba22b005a26f.

Harvey P, Hawkins B. 2008. *Hawke's Bay Regional Council Coastal Hazard Zones Valuation Report*. Napier: Hawke's Bay Regional Council. Retrieved from www.hbrc.govt.nz/assets/Document-Library/Reports/Coastal-Hazards/20080404-WHL-Report-Full.pdf.

Hawkes PJ, Gouldby BR, Tawn JA, Owen MW. 2002. The joint probability of waves and water levels in coastal engineering design. *Journal of Hydraulic Research* 40(3): 241–251.

Hay C, Mitrovica JX, Gomez N, Creveling JR, Austermann JE, Kopp R. 2014. The sea-level fingerprints of ice-sheet collapse during interglacial periods. *Quaternary Science Reviews* 87: 60–69. Retrieved from http://dx.doi.org/10.1016/j.quascirev.2013.12.022.

Hayward C, Simpson L, Wood L. 2004. Still left out in the cold: Problematising participatory research and development. *Sociologia Ruralis* 44(1): 95–108. Retrieved from http://dx.doi.org/10.1111/j.1467-9523.2004.00264.x.

Hemer MA, Fan Y, Mori N, Semedo A, Wang XL. 2013. Projected changes in wave climate from a multi-model ensemble. *Nature Climate Change* 3(5): 471–476. Retrieved from http://dx.doi.org/10.1038/nclimate1791.

Herman JD, Reed PM, Zeff HB, Characklis GW. 2015. How should robustness be defined for water systems planning under change? *Journal of Water Resources Planning and Management-ASCE* 141(10). Retrieved from http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000509.

Hermans LM, Haasnoot M, ter Maat J, Kwakkel JH. 2017. Designing monitoring arrangements for collaborative learning about adaptation pathways. *Environmental Science and Policy* 69: 29-38. Retrieved from: https://doi.org/10.1016/j.envsci.2016.12.005.

Hinkel J, Lincke D, Vafeidis AT, Perrette M, Nicholls RJ, Tol RSJ, Marzeion B, Fettweis X, Ionescu C, Levermann A. 2014. Coastal flood damage and adaptation costs under 21st century sea-level rise. In: *Proceedings of the National Academy of Sciences* 111(9): 3292–3297. Retrieved from http://dx.doi.org/10.1073/pnas.1222469111.

Hoekstra AY. 2012. Computer-supported games and role plays in teaching water management. *Hydrology and Earth System Sciences* 16: 2985–2994. doi: 10.5194/hess-16-2985-2012.

Holling CS. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4(1): 1–23. Retrieved from http://dx.doi.org/10.1146/annurev.es.04.110173.000245.

Horton BP, Rahmstorf S, Engelhart SE, Kemp AC. 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300. *Quaternary Science Reviews* 84: 1–6. Retrieved from http://dx.doi.org/10.1016/j.quascirev.2013.11.002.

Houlié N, Stern TA. 2016. Vertical tectonics at an active continental margin. *Earth and Planetary Science Letters* 457: 292–301. Retrieved from http://dx.doi.org/10.1016/j.epsl.2016.10.018.

Hunter JR. 2015. *Sea-level extremes at four New Zealand tide gauge locations and the impact of future sea-level rise*. Prepared for Office of the Parliamentary Commissioner for the Environment. Wellington: Parliamentary Commissioner for the Environment.

Hurlbert M, Gupta J. 2015. The split ladder of participation: A diagnostic, strategic, and evaluation tool to assess when participation is necessary. *Environmental Science & Policy* 50: 100–113. http://dx.doi.org/10.1016/j.envsci.2015.01.011.

Insurance Council of New Zealand. 2014. *Protecting New Zealand from natural hazards*. Wellington: Insurance Council of New Zealand. Retrieved from www.icnz.org.nz/natural-disaster/protecting-new-zealand-from-natural-hazards/.

International Association of Public Participation. 2014. IAP2 Spectrum of Participation. Retrieved from: www.iap2.org/page/A5.

Intergovernmental Oceanographic Commission. 2016. Tsunami Glossary. Paris: UNESCO.

IPCC. 2000. *Summary for policymakers: Emission scenarios*. A Special Report of IPCC Working Group III. www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.

IPCC. 2007. Summary for Policymakers. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) *Climate change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge:

Cambridge University Press: Cambridge: 996. Available from: www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html.

IPCC. 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

IPCC. 2013a. Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Retrieved from www.ipcc.ch/report/ar5/wg1/.

IPCC. 2013b. Summary for policymakers. In: TF Stocker, D Qin, G-K. Plattner et al (eds) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

IPCC. 2014a. *Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC. Retrieved from http://ar5-syr.ipcc.ch/.

IPCC. 2014b. Summary for policymakers. In: CB Field, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea and LL White (eds) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press: 32. Retrieved from http://ipcc.ch/report/ar5/wg2/.

IPCC. 2014c. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. VR Barros, CB Field, DJ Dokken, MD Mastrandrea, KJ Mach, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea, LL White (eds). Cambridge: Cambridge University Press: 688. Retrieved from http://ipcc.ch/report/ar5/wg2/.

Irvin RA, Stansbury J. 2004. Citizen participation in decision making: Is it worth the effort? *Public Administration Review* 64(1): 55–65. Retrieved from http://dx.doi.org/10.1111/j.1540-6210.2004.00346.x.

Ishihara K. 1985. Stability of natural deposits during earthquakes. In: *Proceedings from 11th International Conference on Soil Mechanics and Foundation Engineering, Volume 1*. San Francisco: CRC Press: 321–376.

Jeffrey L, Fyson C, Alexander R, Gütschow J, Rocha M, Cantzler J, Schaeffer M, Hare B, Hagemann M, Höhne N, van Breevoort P, Blok K. 2015. 2.7°C is not enough – we can get lower. *Climate Action Tracker Update*, 8 December 2015. Retrieved from http://climateactiontracker.org/assets/publications/briefing_papers/CAT_Temp_Update_COP21.pdf.

Jennings R, Shulmeister J. 2002. A field based classification scheme for gravel beaches. *Marine Geology* 186(3–4): 211–228.

Jevrejeva S, Grinsted A, Moore JC. 2014. Upper limit for sea level projections by 2100. *Environmental Research Letters* 9(10): 104008. Retrieved from http://stacks.iop.org/1748-9326/9/i=10/a=104008.

Jevrejeva S, Moore JC, Grinsted A. 2012. Sea level projections to AD2500 with a new generation of climate change scenarios. *Global and Planetary Change* 80–81: 14–20. http://dx.doi.org/10.1016/j.gloplacha.2011.09.006.

Johnston D, Leonard G, Bell R, Stewart C, Hickman M, Thomson J, Kerr J, Glassey R. 2003. *Tabulated results of the 2003 National Coastal Community Survey*. Lower Hutt: Institute of Geological and Nuclear Sciences. Retrieved from http://shop.gns.cri.nz/tabulated-results-of-the-2003-national-coastal-community-survey/.

Jones RN, Patwardhan A, Cohen SJ, Dessai S, Lammel A, Lempert RJ, Mirza MMQ, von Storch H. 2014. Foundations for decision making. In: CB Field, VR Barros, DJ Dokken et al (eds) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Retrieved from http://ipcc.ch/report/ar5/wg2/.

Joughin I, Smith BE, Medley B. 2014. Marine ice sheet collapse potentially under way for the Thwaites Glacier Basin, West Antarctica. *Science* 344(6185): 735–738. Retrieved from http://dx.doi.org/10.1126/science.1249055.

Kasemir B, Jager J, Jaeger CC, Gardner MT. 2003. *Public participation in sustainability science: A handbook*. West Nyack, NY: Cambridge University Press.

Kemp, AC, Horton, BP, Donnelly, JP, Mann, ME, Vermeer, M, Rahmstorf, S. 2011. Climate related sea-level variations over the past two millennia. *Proceedings of the National Academy of Sciences* 108(27): 11017–11022. Retrieved from http://dx.doi.org/10.1073/pnas.1015619108.

Kenderdine SE, Hart DE, Cox RJ, de Lange WP, Smith MH. 2016. *Peer review of the Christchurch Coastal Hazards Assessment Report*. Prepared for the Christchurch City Council. Christchurch: Christchurch City Council.

Kettle NP, Dow K. 2016. The role of perceived risk, uncertainty, and trust on coastal climate change adaptation planning. *Environment and Behavior* 48(4): 579–606.

King DN, Dalton W, Bind J, Srinivasan MS, Duncan M, Skipper A, Ashford-Hosking D, Williams B, Renata H, Baker M. 2012. *Coastal adaptation to climate variability and change: Examining community risk, vulnerability and endurance at Manaia Settlement, Hauraki-Waikato, Aotearoa-New Zealand*. Auckland: NIWA. Retrieved from www.niwa.co.nz/sites/niwa.co.nz/files/niwa_report_akl2012-029.pdf.

King DN, Dalton W, Bind J, Srinivasan MS, Hicks DM, Iti W, Skipper A, Home M, Ashford-Hosking D. 2013. *Coastal adaptation to climate variability and change: Examining community risk, vulnerability and endurance at Mitimiti, Hokianga, Aotearoa-New Zealand*. Auckland: NIWA. Retrieved from www.niwa.co.nz/sites/niwa.co.nz/files/NIWA%20Report%20AKL2013-022_smaller.pdf.

King DN, Dalton W, Home M, Srinivasan M, Bind J, Zammit C, McKerchar A, Ashford-Hosking D, Skipper A. 2011. *Maori community adaptation to climate variability and change: examining risk, vulnerability and adaptive strategies with Ngāti Huirapa at Arowhenua Pā, Te Umu Kaha (Temuka), New Zealand*. Prepared for Te Runanga o Arowhenua Society incorporated and the New Zealand Climate Change Research Institute Victoria University, by NIWA. Auckland: NIWA. Retrieved from www.niwa.co.nz/sites/niwa.co.nz/files/niwa_report_akl2011-015_0.pdf.

King DN, Nichol SL, Hume TM. 2006. Rapid onshore sand flux in a high energy littoral cell: Piha Beach, New Zealand. *Journal of Coastal Research* 22(6): 1360–1369.

King Tides Initiative (n.d). King Tides Auckland. Retrieved from http://auckland.kingtides.org.nz/ (November 2016).

Kirk R. 1992. Experimental beach reconstruction-renourishment on mixed sand and gravel beaches, Washdyke Lagoon, South Canterbury, New Zealand. *Coastal Engineering* 17: 253–277. doi: 10.1016/0378-3839(92)90054-X.

Kitchin R, Tate NJ. 2000. *Conducting research into human geography: Theory, methodology and practice*. Harlow (UK): Prentice Hall: 330. ISBN-13: 978-0582297975.

Komar P. 1998. Beach Processes and Sedimentation. New Jersey: Prentice-Hall Inc.

Kopp RE, Horton RM, Little CM, Mitrovica JX, Oppenheimer M, Rasmussen DJ, Strauss BH, Tebaldi C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future* 2(8): 383–406. Retrieved from http://dx.doi.org/10.1002/2014EF000239.

Kopp RE, Kemp AC, Bittermann K, Horton BP, Donnelly JP, Gehrels WR, Hay CC, Mitrovica JX, Morrow ED, Rahmstor S. 2016. Temperature-driven global sea-level variability in the Common Era. *Proceedings of the National Academy of Sciences* 113(11): E1434–E1441. Retrieved from http://dx.doi.org/10.1073/pnas.1517056113.

Korfmacher KS. 2001. The politics of participation in watershed modelling. *Environmental Management* 27(2): 161–176. Retrieved from http://dx.doi.org/10.1007/s002670010141.

Kousky C, Pratt J, Zeckhauser R. 2010. Virgin versus experienced risks. In: E Michel-Kerjan, P Slovic (eds) *The Irrational Economist: Making decisions in a dangerous world*: 99–106. New York: Public Affairs.

Kunreuther H, Heal G, Allen M, Edenhofer O, Field CB, Yohe G. 2013. Risk management and climate change. *Nature Climate Change* 3(5): 447–450. Retrieved from http://dx.doi.org/10.1038/nclimate1740.

Kwadijk JCJ, Haasnoot M, Mulder JPM, Hoogvliet MMC, Jeuken ABM, van der Krogt RAA, van Oostrom NGC, Schelfhout HA, van Velzen E, van Waveren H, de Wit MJM. 2010. Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. In: *Wiley Interdisciplinary Reviews: Climate Change* 1(5): 729–740. Retrieved from http://dx.doi.org/10.1002/wcc.64.

Kwakkel JH, Walker WE, Haasnoot M. 2016. Coping with the wickedness of public policy problems: Approaches for decision making under deep uncertainty. *Journal of Water Resources Planning and Management-ASCE* 142(3). Retrieved from http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000626.

Land Information New Zealand. 2013. *Interim guideline to sea boundaries and the Marine and Coastal Area (Takutai Moana) Act 2011*. Wellington: Land Information New Zealand. Retrieved from www.linz.govt.nz/regulatory/65705.

Land Information New Zealand. 2016. *Standard for New Zealand Vertical Datum 2016*. Wellington: Land Information New Zealand. Retrieved from www.linz.govt.nz/regulatory/25009.

Lane E, Stephens S, Bell RG. 2011. The future storm-surge climate of New Zealand – A glimpse into the crystal ball. Abstract and presentation to the New Zealand Coastal Society 19th Annual Conference, 7–9 November 2011, Nelson. Abstracts p. 28.

Lawrence J, Blackett P, Cradock-Henry N, Flood S, Greenaway A, Dunningham A. 2016. Synthesis Report RA4: Enhancing capacity and increasing coordination to support decision making. Climate Change Impacts and Implications (CCII) for New Zealand to 2100. MBIE contract C01X1225. 74 pp.

Lawrence J, Haasnoot M. 2017. What it took to catalyse uptake of adaptive pathways planning to address climate change uncertainty. *Environmental Science and Policy* 68: 47-57 (Published online 13 December 2016) Retrieved from http://dx.doi.org/10.1016/j.envsci.2016.12.003.

Laws D, Forester J. 2015. *Conflict, improvisation, governance: Street level practices for urban democracy*. Abingdon (Oxford): Routledge: 372. ISBN: 978-1-13-802567-7.

Le Cozannet G, Rohmer J, Cazenave A, Idier D, van de Wal R, de Winter R, Pedreros R, Balouin Y, Vinchon C, Oliveros C. 2015. Evaluating uncertainties of future marine flooding occurrence as sea-level rises. *Environmental Modelling & Software* 73: 44–56. Retrieved from http://dx.doi.org/10.1016/j.envsoft.2015.07.021.

Lebel L, Anderies JM, Campbell B, Folke C, Hatfield-Dodds S, Hughes TP, Wilson J. 2006. Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society* 11(1): 19. Retrieved from www.ecologyandsociety.org/vol11/iss1/art19/.

Leining C, Kerr S. 2016. *New Zealand's low-emission future: Transformational pathways to 2050*. Outcomes from Motu's Low-Emission Future Dialogue. Motu working paper, 23: 21. Wellington: Motu. Retrieved from http://motu.nz/our-work/environment-and-resources/emission-mitigation/shaping-new-zealands-low-emissions-future/new-zealands-low-emission-future-transformational-pathways-to-2050/.

Lempert RJ, Collins MT. 2007. Managing the risk of uncertain threshold responses: Comparison of robust, optimum, and precautionary approaches. *Risk Analysis* 27(4): 1009–1026. Retrieved from http://dx.doi.org/10.1111/j.1539-6924.2007.00940.x.

Lempert RJ, Groves DG, Popper SW, Bankes SC. 2006. A general, analytic method for generating robust strategies and narrative scenarios. *Management Science* 52(4): 514–528. Retrieved from http://dx.doi.org/10.1287/mnsc.1050.0472.

Lempert RJ, Popper SW, Bankes SC. 2003. *Shaping the next one hundred years: New methods for quantitative, long-term policy analysis*. Santa Monica: RAND Corporation. Retrieved from www.rand.org/pubs/monograph_reports/MR1626.html.

Levermann A, Clark PU, Marzeion B, Milne GA, Pollard D, Radic V, Robinson A. 2013. The multimillennial sea-level commitment of global warming. *Proceedings of the National Academy of Sciences* 110(34): 13745–13750. Retrieved from http://dx.doi.org/10.1073/pnas.1219414110.

Lever-Tracy C. 2016. After Paris – climate disasters and climate change. In: *Proceedings of Australian & New Zealand Disaster and Emergency Management Conference*, 30–31 May 2016.

Lewandowsky S, Risbey JS, Smithson M, Newell BR, Hunter J. 2014. Scientific uncertainty and climate change: Part I. Uncertainty and unabated emissions. *Climatic Change* 124(1): 21–37.

Little CM, Oppenheimer M, Urban NM. 2013. Upper bounds on twenty-first-century Antarctic ice loss assessed using a probabilistic framework. *Nature Climate Change* 3(7): 654–659. http://dx.doi.org/10.1038/nclimate1845.

Local Government New Zealand. 2014. *Managing natural hazard risk in New Zealand – towards more resilient communities. A think-piece for local and central government and others with a role in managing natural hazards*. Wellington: Local Government New Zealand. Retrieved from www.lgnz.co.nz/assets/Publications/Managing-natural-hazards-LGNZ-think-piece.pdf.

Local Government New Zealand. 2016a *Risk financing in local government*. Prepared for Local Government New Zealand by David Middleton, Kestrel Group. Wellington: Local Government New Zealand. Retrieved from www.lgnz.co.nz/home/our-work/publications/risk-financing-in-local-government/.

Local Government New Zealand. 2016b. *The 2050 challenge: future proofing our communities*. Prepared for Local Government New Zealand by Castalia Strategic Advisors. Wellington: Local Government New Zealand. Retrieved from www.lgnz.co.nz/home/our-work/publications/the-2050-challenge-future-proofing-our-communities/.

Lourenço TC, Rovisco A, Groot A, Nilsson C, Füssel H-M, Bree LV, Street RB. 2014. *Adapting to uncertain climate: Lessons from practice*. Switzerland: Springer International Publishing: 182. Retrieved from http://dx.doi.org/10.1007/978-3-319-04876-5.

Lowe JA, Howard TP, Pardaens A, Tinker J, Holt J, Wakelin S, Milne G, Leake J, Wolf J, Horsburgh K, Reeder T, Jenkins G, Ridley J, Dye S, Bradley S. 2009. *UK Climate Projections 09 Science Report: Marine and coastal projections*. Exeter: Meteorological Office Hadley Centre.

Magnan AK, Colombier M, Bille R, Joos F, Hoegh-Guldberg O, Portner H-O, Waisman H, Spencer T, Gattuso J-P. 2016. Implications of the Paris agreement for the ocean. *Nature Climate Change* 6(8): 732–735. Retrieved from http://dx.doi.org/10.1038/nclimate3038.

Manning M, Chapman R, Hales S, Howden-Chapman P, King D, Kjellstrom T, Lawrence J, Lindsay G. 2011. *Synthesis: Community vulnerability, resilience and adaptation to climate change in New Zealand*. Wellington: New Zealand Climate Change Research Institute, Victoria University of Wellington. Retrieved from www.victoria.ac.nz/sgees/research-centres/documents/synthesis-community-vulnerability-resilience-and-adaptation-to-climate-change-in-nz.pdf.

Manning M, Lawrence J, King DN, Chapman R. 2015. Dealing with changing risks: A New Zealand perspective on climate change adaptation. *Regional Environmental Change* 15: 581–594. Retrieved from http://link.springer.com/article/10.1007/s10113-014-0673-1.

Marcos M, Marzeion B, Dangendorf S, Slangen ABA, Palanisamy H, Fenoglio-Marc L. 2016. Internal variability versus anthropogenic forcing on sea level and its components. *Surveys in Geophysics*: 1–20. Retrieved from http://dx.doi.org/10.1007/s10712-016-9373-3.

Mastrandrea MD, Field CB, Stocker TF, Edenhofer O, Ebi KL, Frame DJ, Held H, Kriegler E, Mach KJ, Matschoss PR, Plattner G-K, Yohe GW, Zwiers FW. 2010. *Guidance note for Lead Authors of the IPCC Fifth Assessment Report on consistent treatment of uncertainties*. Geneva: Intergovernmental Panel on Climate Change.

McNie EC. 2007. Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. *Environmental Science & Policy* 10: 17–38. Retrieved from http://dx.doi.org/10.1016/j.envsci.2006.10.004.

Meisler H, Leahy PP, Knobel LL. 1984. *Effect of eustatic sea-level changes on saltwater-freshwater relations in the Northern Atlantic coastal plain: US Geological Survey Water-Supply Paper 225*. Alexandria: US Geological Survey and Department for the Interior. Retrieved from https://pubs.er.usgs.gov/publication/wsp2255.

Mengel M, Levermann A, Frieler K, Robinson A, Marzeion B, Winkelmann R. 2016. Future sea level rise constrained by observations and long-term commitment. *Proceedings of the National Academy of Sciences* 113(10): 2597–2602. Retrieved from http://dx.doi.org/10.1073/pnas.1500515113.

Meyssignac B, Cazenave A. 2012. Sea level: A review of present-day and recent-past changes and variability. *Journal of Geodynamics* 58: 96–109. Retrieved from http://dx.doi.org/10.1016/j.jog.2012.03.005.

Milne GA, Gehrels WR, Hughes CW, Tamisiea ME. 2009. Identifying the causes of sea-level change. *Nature Geosciences* 2(7): 471–478. Retrieved from http://dx.doi.org/10.1038/ngeo544.

Mimura N, Pulwarty RS, Duc DM, Elshinnawy I, Redsteer MH, Huang HQ, Nkem JN, Sanchez Rodriguez RA. 2014. Adaptation planning and implementation. In: CB Field, VR Barros, DJ Dokken et al (eds) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Retrieved from http://ipcc.ch/report/ar5/wg2/.

Ministry for the Environment. 2004. *The Waikato Weather Bomb: Understanding the impact*. Retrieved from www.mfe.govt.nz/publications/climate-change/waikato-weather-bomb-understanding-impact (November 2016).

Ministry for the Environment. 2008a. *Coastal hazards and climate change: A guidance manual for local government in New Zealand*. Wellington: Ministry for the Environment. Retrieved from www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-manual-local-government-ne-0.

Ministry for the Environment. 2008b. *Climate change effects and impacts assessment: A guidance manual for local government in New Zealand*. Prepared for the Ministry for the Environment by NIWA, MWH, and Earthwise Consulting. Wellington: Ministry for the Environment. Retrieved from www.mfe.govt.nz/publications/climate-change/climate-change-effects-and-impacts-assessment-guidance-manual-local-6.

Ministry for the Environment. 2008c. *Preparing for climate change: A guide for local government in New Zealand*. Wellington: Ministry for the Environment.

Ministry for the Environment. 2010. *Preparing for Future Flooding: A guide for local government in New Zealand*. Wellington: Ministry for the Environment.

Ministry for the Environment. 2016. *Climate change projections for New Zealand: Atmospheric projections based on simulations undertaken for the IPCC Fifth Assessment*. Wellington: Ministry for the Environment. Retrieved from www.mfe.govt.nz/publications/climate-change/climate-change-projections-new-zealand.

Ministry for the Environment. 2017. *Preparing for coastal change*. Wellington: Ministry for the Environment.

Ministry of Civil Defence and Emergency Management. (n.d). *Local and regional hazard risk reduction*. Retrieved from www.civildefence.govt.nz/cdem-sector/cdem-framework/the-4rs/reduction/local-and-regional-hazard-risk-reduction/ (6 November 2016).

Ministry of Civil Defence and Emergency Management. 2016. *Tsunami Evacuation Zones: Director's Guideline for Civil Defence Emergency Management*. Wellington: Ministry of Civil Defence and Emergency Management. Retrieved from www.civildefence.govt.nz/assets/Uploads/publications/dgl-08-16-Tsunami-Evacuation-Zones.pdf.

Ministry of Infrastructure and the Environment and Ministry of Economic Affairs. 2014. Delta Programme 2015; Working on the delta. Retrieved from http://english.deltacommissaris.nl/delta-programme.

Mitrovica JX, Gomez N, Morrow E, Hay C, Latychev K, Tamisiea ME. 2011. On the robustness of predictions of sea level fingerprints. *Geophysical Journal International* 187(2): 729–742. Retrieved from http://dx.doi.org/10.1111/j.1365-246X.2011.05090.x.

Moore JC, Grinsted A, Zwinger T, Jevrejeva S. 2013. Semiempirical and process-based global sea level projections. *Reviews of Geophysics* 51(3): 484–522. Retrieved from http://dx.doi.org/10.1002/rog.20015.

Morlighem M, Rignot E, Mouginot J, Seroussi H, Larour E. 2014. Deeply incised submarine glacial valleys beneath the Greenland Ice Sheet. *Nature Geoscience* 7: 418–422.

Moser SC. 2016. Reflections on climate change communication research and practice in the second decade of the 21st century: What more is there to say? *Wiley Interdisciplinary Review: Climate Change* 7: 345–369. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/wcc.403/abstract.

Moser SC, Dilling L. 2007. Toward the social tipping point: creating a climate for change. In: SC Moser, L Dilling (eds) *Creating a climate for change: Communicating climate change and facilitating social change*: 491–516. Cambridge: Cambridge University Press. ISBN-13: 9780521869232.

Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, van Vuuren DP, Carter TR, Emori S, Kainuma M, Kram T, Meehl GA, Mitchell JFB, Nakicenovic N, Riahi K, Smith SJ, Stouffer RJ, Thomson AM, Weyant JP, Wilbanks TJ. 2010. The next generation of scenarios for climate change research and assessment. *Nature* 463(7282): 747–756. Retrieved from www.nature.com/nature/journal/v463/n7282/suppinfo/nature08823_S1.html.

Muro M, Jeffrey P. 2008. A critical review of the theory and application of social learning in participatory natural resource management processes. *Journal of Environmental Planning and Management* 51(3): 325–344. Retrieved from http://dx.doi.org/10.1080/09640560801977190.

National Academies of Sciences. 2016. *Characterizing risk in climate change assessments: Proceedings of a workshop*. Washington DC: The National Academies Press. doi: 10.17226/23569. www.nap.edu/download/23569.

National Research Council. 2012. *Sea-level rise for the coasts of California, Oregon, and Washington: Past, present, and future*. Washington DC: The National Academies Press. Retrieved from http://dx.doi.org/10.17226/13389.

National Science Challenges. *Vision Matauranga*. (n.d). Retrieved from www.deepsouthchallenge.co.nz/programmes/vision-matauranga (1 December 2016).

New Zealand Geotechnical Society and Ministry of Business, Innovation and Employment. 2016. *Earthquake Geotechnical Engineering Practice in New Zealand. Module 3: Identification, assessment and mitigation of liquefaction hazards*. Wellington: New Zealand Geotechnical Society and Ministry of Business, Innovation and Employment.

NCCARF. 2016. *CoastAdapt beta release: Online coastal climate risk management framework*. Prepared by the National Climate Change Adaptation Research Facility (NCCARF), Griffith University Gold Coast Campus, Gold Coast, Australia. www.nccarf.edu.au/CoastAdapt-beta-release.

Nicholls RJ, Hanson SE, Lowe JA, Warrick RA, Lu X, Long AJ, Carter TR. 2011a. *Constructing sea-level scenarios for impact and adaptation assessment of coastal areas: A guidance document*. Prepared by IPCC Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA), IPCC Working Group II: 47.

Nicholls RJ, Marinova N, Lowe JA, Brown S, Vellinga P, de Gusmão D, Hinkel J, Tol RSJ. 2011b. Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369(1934): 161–181. Retrieved from http://dx.doi.org/10.1098/rsta.2010.0291.

NIWA. 2009. *Nga Waihotanga Iho – Iwi estuarine monitoring toolkit*. Retrieved from www.niwa.co.nz/te-k%C5%ABwaha/research-projects/ng%C4%81-waihotanga-iho-iwi-estuarine-monitoring-toolkit (November 2016).

NIWA. 2016. *New Zealand temperature record: Seven-station Series*. Retrieved October 2016: www.niwa.co.nz/climate/information-and-resources/nz-temperature-record.

NIWA. (n.d). *'Flockton Basin' building impact and loss estimates for the March 5th 2014 Christchurch Flood Event*. Retrieved from https://wiki-riskscape.niwa.co.nz/images/7/7a/%27Flockton_Basin%E2%80%99_building_impact_and_loss_estimates_for_the_March_5th_2014_Christchurch_flood_event.pdf (November 2016).

NIWA and GNS Science. (n.d). *RiskScape*. Retrieved from www.riskscape.org.nz (November 2016).

Olsson P, Gunderson LH, Carpenter SR, Ryan P, Lebel L, Folke C, Holling CS. 2006. Shooting the rapids: Navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society* 11(1): 18. Retrieved from http://www.ecologyandsociety.org/vol11/iss1/art18/.

Oppenheimer M, Little CM, Cooke RM. 2016. Expert judgement and uncertainty quantification for climate change. *Nature Climate Change* 6(5): 445–451. Retrieved from http://dx.doi.org/10.1038/nclimate2959.

Pahl-Wostl C, Hare M. 2004. Processes of social learning in integrated resources management. *Journal of Community & Applied Social Psychology* 14: 193–206. Retrieved from http://dx.doi.org/10.1002/casp.774.

Paolo FS, Fricker HA, Padman L. 2015. Volume loss from Antarctic ice shelves is accelerating. *Science* 348(6232): 327–331. Retrieved from http://dx.doi.org/10.1126/science.aaa0940.

Parliamentary Commissioner for the Environment. 2014. *Changing climate and rising seas: Understanding the science*. Wellington: Parliamentary Commissioner for the Environment. Retrieved from www.pce.parliament.nz/media/1258/changing-climate-and-rising-seas-web.pdf.

Parliamentary Commissioner for the Environment. 2015. *Preparing New Zealand for rising seas: certainty and uncertainty*. Wellington: Parliamentary Commissioner for the Environment. Retrieved from www.pce.parliament.nz/publications/preparing-new-zealand-for-rising-seas-certainty-and-uncertainty.

Parry M, Arnell N, Berry P, Dodman D, Fankhauser S, Hope C, Kovats S, Nicholls R, Satterthwaite D, Tiffin R, Wheeler T. 2009. *Assessing the costs of adaptation to climate change: A review of the UNFCCC and other recent estimates*. London: International Institute for Environment and Development, Imperial College London and the Grantham Institute for Climate Change: 111. ISBN: 978-1-84369-745-9.

Pearson C. 2004. *Joint probabilities of sea levels and Buller River floods*. NIWA Client Report CHC2004–092. Wellington: NIWA.

Perrette M, Landerer F, Riva R, Frieler K, Meinshausen M. 2013. A scaling approach to project regional sea level rise and its uncertainties. *Earth System Dynamics* 4(1): 11–29. Retrieved from http://dx.doi.org/10.5194/esd-4-11-2013.

Power WL. 2013. *Review of tsunami hazard in New Zealand (2013 update)*. Wellington: GNS Science. Retrieved from www.civildefence.govt.nz/assets/Uploads/publications/GNS-CR2013-131-Tsunami-Report-Full.pdf.

Pugh DT. 1996. *Tides, surges and mean sea-level* (reprinted with corrections). Chichester: John Wiley & Sons Ltd: 486. http://eprints.soton.ac.uk/19157/1/sea-level.pdf.

Quality Planning. (n.d). *Climate change*. Retrieved from www.qualityplanning.org.nz/index.php/planning-tools/climate-change (November 2016).

Quality Planning. (n.d). *Introduction and the framework and principles for coastal management*. Retrieved from www.qualityplanning.org.nz/index.php/planning-tools/coastal-land-development/introduction-and-the-framework-and-principles-for-coastal-management (November 2016).

Quality Planning. (n.d). *Natural hazards*. Retrieved from www.qualityplanning.org.nz/index.php/planning-tools/natural-hazards (November 2016).

Quality Planning. (n.d). Treaty of Waitangi obligations. Retrieved from www.qualityplanning.org.nz/index.php/plan-development-components/consultation-with-tangata-whenua/context-for-consultation-with-tangata-whenua (November 2016).

Quilter P. 2015. The effect of sea level rise on liquefaction vulnerability: A case study for consideration of development on coastal plains and reclamations. In: *Proceedings of the Australasian Coasts and Ports Conference 2015*. Auckland.

Rahmstorf S, Perrette M, Vermeer M. 2012. Testing the robustness of semi-empirical sea level projections. *Climate Dynamics* 39(3): 861–875. Retrieved from http://dx.doi.org/10.1007/s00382-011-1226-7.

Ramsay D, Stephens S. 2006. Double trouble: How often do large waves occur with high water levels? *Coastal News* 32: 4–5. Published by the NZ Coastal Society, June 2006.

Ramsay DLG, Gibberd B, Dahm J, Bell RG. 2012. *Defining coastal hazard zones and setback lines: A guide to good practice*. Hamilton: NIWA. Retrieved from www.envirolink.govt.nz/Envirolink-tools/natural-hazard-tools/.

Ranasinghe R, McLoughlin R, Short A, Symonds G. 2004. The Southern Oscillation Index, wave climate, and beach rotation. *Marine Geology* 204(3): 273–287. http://dx.doi.org/10.1016/S0025-3227(04)00002-7.

Ranger N, Reeder T, Lowe J. 2013. Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: Four innovations of the Thames Estuary 2100 Project. *EURO Journal on Decision Processes* 1(3): 233–262. Retrieved from http://dx.doi.org/10.1007/s40070-013-0014-5.

Reager JT, Gardner AS, Famiglietti JS, Wiese DN, Eicker A, Lo M-H. 2016. A decade of sea level rise slowed by climate-driven hydrology. *Science* 351(6274): 699–703. Retrieved from http://dx.doi.org/10.1126/science.aad8386.

Reed MS, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J, Prell C, Quinn CH, Stringer LC. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management* 90(5): 1933–1949. Retrieved from http://dx.doi.org/10.1016/j.jenvman.2009.01.001.

Reeder T, Ranger N. 2010. *How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project*. Washington DC: World Resources Report. Retrieved from www.wri.org/sites/default/files/uploads/wrr_reeder_and_ranger_uncertainty.pdf.

Reid H, Alam M, Berger R, Cannon T, Milligan A. 2009. *Community-based adaptation to climate change* (Vol PLA 60): London: International Institute for Environment and Development. www.iied.org/pla-60-community-based-adaptation-climate-change.

Reinen-Hamill RH, Hegan B, Shand T. 2006. *Regional assessment of areas susceptible to coastal erosion*. Prepared for Auckland Regional Council by Tonkin+Taylor Ltd. Auckland: Auckland Regional Council.

Reisinger A, Kitching RL, Chiew F, Hughes L, Newton PCD, Schuster SS, Tait A, Whetton P. 2014. Australasia. In: VR Barros, CB Field, DJ Dokkenet al (eds) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Rhein M, Rintoul SR, Aoki S, Campos E, Chambers D, Feely RA, Gulev S, Johnson GC, Josey SA, Kostianoy A, Mauritzen C, Roemmich D, Talley LD, Wang F. 2013. *Observations: Oceans. Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Retrieved from http://dx.doi.org/10.1017/CBO9781107415324.010.

Riahi K, Rao S, Krey V, Cho C, Chirkov V, Fischer G, Kindermann G, Nakicenovic N, Rafaj P. 2011. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *Climatic Change* 109(1): 33–57. Retrieved from http://dx.doi.org/10.1007/s10584-011-0149-y.

Rietbroek R, Brunnabend S-E, Kusche J, Schröter J, Dahle C. 2016. Revisiting the contemporary sea-level budget on global and regional scales. In: *Proceedings of the National Academy of Sciences* 113(6): 1504–1509. Retrieved from http://dx.doi.org/10.1073/pnas.1519132113.

Rignot E, Mouginot J, Morlighem M, Seroussi H, Scheuchl B. 2014. Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011. *Geophysical Research Letters* 41(10): 3502–3509. Retrieved from http://dx.doi.org/10.1002/2014GL060140.

Ritz C, Edwards TL, Durand G, Payne AJ, Peyaud V, Hindmarsh RCA. 2015. Potential sea-level rise from Antarctic ice-sheet instability constrained by observations. *Nature* 528(7580): 115–118. Retrieved from http://dx.doi.org/10.1038/nature16147.

Robinson B, Stephens SA, Gorman RM. 2014. *Extreme sea-level elevations from storm-tides and waves: Tasman and Golden Bay coastlines*. Prepared for Tasman District Council by NIWA. Hamilton: NIWA.

Robinson B, Stephens SA. 2015. *Nelson extreme storm tide plus wave setup and runup*. Prepared for Nelson City Council by NIWA. Hamilton: NIWA.

Rogelj J, den Elzen M, Höhne N, Fransen T, Fekete H, Winkler H, Schaeffer R, Sha F, Riahi K, Meinshausen M. 2016. Paris Agreement climate proposals need a boost to keep warming well below 2°C. *Nature* 534: 631–639.

Rosendahl Appelquist L, Halsnæs K. 2015. The Coastal Hazard Wheel system for coastal multi-hazard assessment and management in a changing climate. *Journal of Coastal Conservation* 19(2): 157–179.

Rotzoll K, Fletcher CH. 2013. Assessment of groundwater inundation as a consequence of sea-level rise. *Nature Climate Change* 3(5): 477–481. Retrieved from www.nature.com/nclimate/journal/v3/n5/abs/nclimate1725.html#supplementary-information.

Rouse HL, Blackett P. 2011. *Engaging communities: Making it work. Coastal Adaptation to Climate Change*. Christchurch: NIWA. Retrieved from www.niwa.co.nz/sites/niwa.co.nz/files/making_it_work_final_december2011.pdf.

Rouse HL, Blackett P, Hume TM, Bell RG, Ramsay D, Rickard D, Smith E, Dahm J, Wishart P, Singleton P, Pickett V. 2011. *Engaging with communities on coastal adaptation to climate change: Whitianga experience*. Auckland: NIWA.

Rouse HL, Blackett P, Hume TM, Bell RG, Britton R, Dahm J. 2013. Coastal adaptation to climate change: A New Zealand story. In: DC Conley, G Masselink, PE Russell, TJ O'Hare (eds) *Proceedings 12th International Coastal Symposium (Plymouth, England), Journal of Coastal Research, Special Issue No. 65*: 1957–1962.

Rouse HL, Bell RG, Lundquist CJ, Blackett PE, Hicks DM, King DN. 2016. Coastal adaptation to climate change in Aotearoa-New Zealand. *New Zealand Journal of Marine and Freshwater Research* 1–40. Retrieved from http://dx.doi.org/10.1080/00288330.2016.1185736.

Rumore D, Schenk T, Susskind L. 2016. Role-play simulations for climate change adaptation education and engagement. *Nature Climate Change* 6: 745-750. doi: 10.1038/nclimate3084.

Sanderson BM, O'Neill BC, Tebaldi C. 2016. What would it take to achieve the Paris temperature targets? *Geophysical Research Letters* 43(13): 7133–7142. Retrieved from http://dx.doi.org/10.1002/2016GL069563.

Schellnhuber HJ, Rahmstorf S, Winkelmann R. 2016. Why the right climate target was agreed in Paris. *Nature Climate Change* 6(7): 649–653. Retrieved from http://dx.doi.org/10.1038/nclimate3013.

Schmidt J, Matcham I, Reese S, King A, Bell R, Henderson R, Smart G, Cousins J, Smith W, Heron D. 2011. Quantitative multi-risk analysis for natural hazards: A framework for multi-risk modelling. *Natural Hazards* 58(3): 1169–1192. doi: 10.1007/s11069-011-9721-z.

Schneider PP. 2014. *Local reality and the climate change adaptation dilemma: Beyond technical fixes and 'business as usual'*. Palmerston North: Massey University. Retrieved from http://mro.massey.ac.nz/handle/10179/5977.

Serrao-Neumann S, Harman B, Leitch A, Low Choy D. 2015. Public engagement and climate adaptation: Insights from three local governments in Australia. *Journal of Environmental Planning and Management* 58: 1196–1216. doi: 10.1080/09640568.2014.920306.

Shand TI, Knook P, Reinen-Hamill R. 2014. *Coastal erosion hazard zone assessment for selected Northland sites*. Report prepared Northland Regional Council by Tonkin+Taylor Ltd. Whangarei: Northland Regional Council.

Sheppard SRJ, Shaw A, Flanders D, Burch S, Wiek A, Carmichael J, Robinson J, Cohen S. 2011. Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. *Futures* 43: 400–412. Retrieved from www.sciencedirect.com/science/article/pii/S0016328711000103.

Slangen ABA, Adloff F, Jevrejeva S, Leclercq PW, Marzeion B, Wada Y, Winkelmann R. 2016a. A review of recent updates of sea-level projections at global and regional scales. *Surveys in Geophysics*: 1–22. Retrieved from http://dx.doi.org/10.1007/s10712-016-9374-2.

Slangen ABA, Carson M, Katsman CA, van de Wal RSW, Köhl A, Vermeersen LLA, Stammer D. 2014. Projecting twenty-first century regional sea-level changes. *Climatic Change* 124(1): 317–332. Retrieved from http://dx.doi.org/10.1007/s10584-014-1080-9.

Slangen ABA, Church JA, Agosta C, Fettweis X, Marzeion B, Richter K. 2016b. Anthropogenic forcing dominates global mean sea-level rise since 1970. *Nature Climate Change* 6(7): 701–705. Retrieved from http://dx.doi.org/10.1038/nclimate2991.

Slangen ABA, Katsman CA, van de Wal RSW, Vermeersen LLA, Riva REM. 2012. Towards regional projections of twenty-first century sea-level change based on IPCC SRES scenarios. *Climate Dynamics* 38(5): 1191–1209. Retrieved from http://dx.doi.org/10.1007/s00382-011-1057-6.

Smith MS, Horrocks L, Harvey A, Hamilton C. 2011. Rethinking adaptation for a 4°C world. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369(1934): 196–216. Retrieved from http://dx.doi.org/10.1098/rsta.2010.0277.

Stephens SA. 2015. *The effect of sea-level rise on the frequency of extreme sea levels in New Zealand*. Prepared by NIWA for the Parliamentary Commissioner for the Environment. Wellington: Parliamentary Commissioner for the Environment. Retrieved from www.pce.parliament.nz/media/1382/the-effect-of-sea-level-rise-on-the-frequency-of-extreme-sea-levels-in-new-zealand-niwa-2015.pdf.

Stephens SA. 2016. Advice on how to use calculations of wave runup elevation, and how to apply freeboard, when developing resource and building consent applications to build near the coast. Letter to Gisborne District Council, 8 August 2016: 6.

Stephens SA, Allis M, Robinson B, Gorman RM. 2015a. *Storm-tides and wave runup in the Canterbury Region*. NIWA Client Report to Environment Canterbury, HAM2015-129: 133.

Stephens S, Bell R, Lawrence J. 2017. Applying principles of uncertainty within coastal hazard assessments to better support coastal adaptation. *Journal of Marine Science and Engineering* 5(3): 40. Retrieved from http://www.mdpi.com/2077-1312/5/3/40.

Stephens SA, Robinson B, Bell RG. 2015b. *Analysis of Whitianga, Tararu and Kawhia sea-level records to 2014*. NIWA Client Report to Waikato Regional Council, HAM2015-046: 98.

Stephens SA, Robinson B, Gorman RM. 2014. *Extreme sea-level elevations from storm-tides and waves along the Gisborne District coastline*. NIWA Client Report to Gisborne District Council HAM2014-052: 106.

Stephens SA, Wadhwa S, Gorman R, Goodhue N, Pritchard M, Ovenden R, Reeve G. 2013. *Coastal inundation by storm-tides and waves in the Auckland Region*. Prepared for Auckland Council by NIWA. Auckland: Auckland Council.

Stephens SA, Wadhwa S, Tuckey B. 2016. *Coastal inundation by storm-tides and waves in the Auckland Region*. Prepared by the National Institute of Water and Atmospheric Research and DHI Ltd for Auckland Council. Auckland Council Technical Report TR2016/017.

Stewart C, Becker JS, Coomer M, Wilson T, Davies A, Hume T. 2007. *Coastal management in the Waikato: A study of the views of Coromandel beachgoers and residents on coastal erosion and its management*. Lower Hutt: Institute of Geological and Nuclear Sciences. Retrieved from www.massey.ac.nz/massey/fms/Colleges/College%20of%20Humanities%20and%20Social%20Sciences/Psychology/Disasters/pubs/GNS/2007/SR%202007-021_Coromandel_beachgoer_interviews_compressedversion.pdf?2D270087F220B02096617E9EA3B9CAAF.

Stewart C, Blackett P, Reese S, Becker JS, Coomer M, Hume T. 2010. *Mapua/Ruby bay coastal management study: Preliminary findings*. Lower Hutt: Institute of Geological and Nuclear Sciences. Retrieved from http://shop.gns.cri.nz/mapua-ruby-bay-coastal-management-study-preliminary-findings/.

Stewart C, Leonard G, Johnston D, Hume T. 2005. *The 2003 National Coastal Community Survey: Results for Waikato beach communities*. Lower Hutt: Institute of Geological and Nuclear Sciences. Retrieved from http://shop.gns.cri.nz/the-2003-national-coastal-community-survey-results-for-waikato-beach-communities/.

Stive MJF. 2004. How important is global warming for coastal erosion? *Climatic Change* 64(1): 27–39. doi: 10.1023/B:CLIM.0000024785.91858.1d.

Stocker TF, Qin D, Plattner G-K, Alexander LV, Allen SK, Bindoff NL, Bréon F-M, … Xie S-P. 2014. Technical Summary. In: TF Stocker, D Qin, G-K Plattner et al (eds) *Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Retrieved from http://dx.doi.org/10.1017/CBO9781107415324.005.

Strauss BH, Kulp S, Levermann A. 2015. Carbon choices determine US cities committed to futures below sea level. *Proceedings of the National Academy of Sciences* 112(44): 13508–13513. Retrieved from http://dx.doi.org/10.1073/pnas.1511186112.

Stringer LC, Dougill AJ, Fraser E, Hubacek K, Prell C, Reed M. 2006. Unpacking "Participation" in the adaptive management of social–ecological systems: A critical review. *Ecology and Society* 11(2): 39. Retrieved from www.ecologyandsociety.org/vol11/iss2/art39/.

Swales A, Denys P, Pickett VI, Lovelock CE. 2016. Evaluating deep subsidence in a rapidly-accreting mangrove forest using GPS monitoring of surface-elevation benchmarks and sedimentary records. *Marine Geology* 380: 205–218. Retrieved from http://dx.doi.org/10.1016/j.margeo.2016.04.015.

Swart R, Biesbroek R, Lourenço TC. 2014. Science of adaptation to climate change and science for adaptation. *Frontiers in Environmental Science* 2(29): 8. Retrieved from http://dx.doi.org/10.3389/fenvs.2014.00029.

Sweet WV, Park J. 2014. From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. *Earth's Future* 2(12): 579–600.

Sweet WV, Park J, Marra J, Zervas C, Gill S. 2014. *Sea level rise and nuisance flood frequency changes around the United States: NOAA Technical Report NOS CO-OPS 073*. Maryland: National Oceanic and Atmospheric Administration. Retrieved from http://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf.

Thames Coromandel District Council. 2012. *Te Puru flood mitigation works completed*. Retrieved from www.tcdc.govt.nz/Your-Council/News-and-Media/News-and-Public-Notices/News-Archived-Articles/June-2012/Te-Puru-flood-mitigation-works-completed/ (November 2016).

Thompson PR, Hamlington BD, Landerer FW, Adhikari S. 2016. Are long tide gauge records in the wrong place to measure global mean sea level rise? *Geophysical Research Letters* 43: L070552. doi: 10.1002/2016GL070552.

Tippett J, Handley JF, Ravetz JR. 2007. Meeting the challenges of sustainable development: A conceptual appraisal of a new methodology for participatory ecological planning. *Progress in Planning* 67: 9–98. Retrieved from http://dx.doi.org/10.1016/j.progress.2006.12.004.

Tonkin+Taylor. 2016a. *Clifton to Tangoio Coastal Hazards Strategy 2120: Coastal hazard assessment*. Prepared by Tonkin+Taylor Ltd for Hawke's Bay councils (HBRC, NCC, HDC). www.hbcoast.co.nz/assets/Document-Library/Technical-Documents/Coastal-Hazard-Assessment.pdf.

Tonkin+Taylor. 2016b. *Hawke Bay Coastal Strategy: Coastal risk assessment*. Prepared by Tonkin+Taylor for Hawke's Bay Regional Council. Retrieved from www.hbrc.govt.nz/assets/Document-Library/Reports/Coastal-Hazards/2016.SHAF.Risk-Assessment-Report.R5.pdf.

Torresan S, Critto A, Rizzi J, Marcomini A. 2012. Assessment of coastal vulnerability to climate change hazards at the regional scale: the case study of the North Adriatic Sea. *Natural Hazards Earth System Science* 12(7): 2347–2368.

Trusel LD, Frey KE, Das SB, Karnauskas KB, Munneke PK, van Meijgaard E, van den Broeke MR. 2015. Divergent trajectories of Antarctic surface melt under two twenty-first-century climate scenarios. *Nature Geoscience* 8: 927–932. doi: 10.1038/ngeo2563.

Tschakert P, Dietrich KA. 2010. Anticipatory learning for climate change adaptation and resilience. *Ecology and Society* 15(2): Article 11.

Turbott C, Stewart A. 2006. *Managed retreat from coastal hazards: Options for implementation*. Environment Waikato Technical Report, 2006/48: 89. Environment Waikato, Hamilton.

Turner IL, Nielsen P. 1997. Rapid watertable fluctuations: Implications for swash zone sediment mobility. *Coastal Engineering* 32: 45–59.

UK Climate Projections (UKCP09). 2009. *Reports & guidance*. Retrieved from http://ukclimateprojections.metoffice.gov.uk/22530 (November 2016).

UNEP 2017. *The Emissions Gap Report 2017*. United Nations Environment Programme (UNEP), Nairobi. Retrieved from www.unenvironment.org/resources/emissions-gap-report

UN-Habitat 2014. *Planning for climate change: A strategic, values-based approach for urban planners*. Cities and Climate Change Initiative, Tool Series: 148. Nairobi (Kenya): United Nations Human Settlements Programme (UN-Habitat). Retrieved from http://unhabitat.org/books/planning-for-climate-change-a-strategic-values-based-approach-for-urban-planners-cities-and-climate-change-initiative/.

UN-Habitat. 2015. *International guidelines on urban and territorial planning*. Report HS/059/15E: 40. Nairobi (Kenya), UN-Habitat. Retrieved from http://unhabitat.org/books/international-guidelines-on-urban-and-territorial-planning/.

UNFCCC. 2015. *Adoption of the Paris Agreement. Proposal by the President, Draft decision -/CP.21*. Geneva: United Nations. Retrieved from https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

United Nations. 1992. *The Rio Declaration on Environment and Development*. Geneva: United Nations. Retrieved from www.unesco.org/education/information/nfsunesco/pdf/RIO_E.PDF.

United Nations. 2015. *Sendai Framework for Disaster Risk Reduction 2015–2030*. Geneva: United Nations. Retrieved from www.unisdr.org/we/inform/publications/43291.

United Nations General Assembly. 1992. Report of the United Nations Conference on Environment and Development.

US Army Corps of Engineers. 2014. *Procedures to evaluate sea level change: Impacts, responses, and adaptation. Engineer Technical Letter ETL-1100-2-1: 254*. Washington DC: US Army Corps of Engineers. Retrieved from www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1100-2-1.pdf.

US Department of Transportation. 2014. *Highways in the coastal environment: Assessing extreme events. Hydraulic Engineering Circula*r 25(2): 123. Washington DC: US Department of Transportation. Retrieved from www.fhwa.dot.gov/engineering/hydraulics/pubs/nhi14006/nhi14006.pdf.

US Environmental Protection Agency. 2016. Updated global mean sea level from Church and White (2011), www.epa.gov/sites/production/files/2016-08/sea-level_fig-1.csv (accessed August 2016).

Valkering P, van der Brugge R, Offermans A, Haasnoot M, Vreugdenhil H. 2012. A perspective-based simulation game to explore future pathways of a water-society system under climate change. *Simulation and Gaming* 44(2-3): 366–390. doi: 10.1177/1046878112441693.

Van der Wal M, de Kraker J, Broeze C, Kirschner P, Valkering P. 2016. Can computer models be used for social learning? A serious game in water management. *Environmental Modelling and Software* 75: 119–132. http://dx.doi.org/10.1016/j.envsoft.2015.10.008.

Van Deursen W. 1995. *Geographical Information Systems and dynamic models: Development and application of a prototype spatial modelling language*. University of Utrecht, The Netherlands: 206. www.carthago.nl/__miracle/doc/thesis1.pdf.

Van Pelt SC, Haasnoot M, Arts B, Ludwig F, Swart R, Biesbroek R. 2015. Communicating climate (change) uncertainties: Simulation games as boundary objects. *Environmental Science & Policy* 45: 41–52. http://dx.doi.org/10.1016/j.envsci.2014.09.004.

van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram T, Krey V, Lamarque J-F, Masui T, Meinshausen M, Nakicenovic N, Smith SJ, Rose SK. 2011. The representative concentration pathways: An overview. *Climatic Change* 109(1): 5–31. Retrieved from http://dx.doi.org/10.1007/s10584-011-0148-z.

Vandenbeld A, MacDonald J. 2013. Fostering community acceptance of managed retreat in New Zealand. In: J Palutikof, S Boulter, A Ash, M Stafford Smith, M Parry, M Waschka and D Guitart (eds) *Climate Adaptation Futures*: 161–166. UK: Wiley-Blackwell.

Velicogna I, Sutterley TC, van den Broeke MR. 2014. Regional acceleration in ice mass loss from Greenland and Antarctica using GRACE time-variable gravity data. *Geophysical Research Letters* 41(22): 8130–8137. Retrieved from http://dx.doi.org/10.1002/2014GL061052.

Videira N, Van den Belt M, Antunes R, Santos R, Boumans R. 2011. Integrated modelling of coastal and estuarine ecosystem services. In: D McLusky, E Wolanski, M Van den Belt, R Costanza (eds) *Treatise on Estuarine and Coastal Science*. London: Academic Press.

Voinov A, Bousquet F. 2010. Modelling with stakeholders. *Environmental Modelling and Software* 25: 1268–1281. Retrieved from http://dx.doi.org/10.1016/j.envsoft.2010.03.007.

Wahl T, Chambers DP. 2016. Climate controls multidecadal variability in US extreme sea level records. *Journal of Geophysical Research-Oceans* 121(2): 1274–1290.

Waikato Regional Council. (n.d). Coastal Inundation Tool. Retrieved from www.waikatoregion.govt.nz/coastal-inundation-tool/ (November 2016).

Walkden MJ, Dickson ME. 2008. Equilibrium erosion of soft rock shores with a shallow or absent beach under increased sea level rise. *Marine Geology* 251(1–2): 75–84.

Walker WE, Harremoës P, Rotmans J, van der Sluijs JP, van Asselt MBA, Janssen P, Krayer von Krauss MP. 2003. Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment* 4(1): 5–17.

Walker WE, Lempert RJ, Kwakkel JH. 2013. Deep uncertainty. In: SI Gass and MC Fu (eds) *Encyclopedia of Operations Research and Management Science*. New York: Springer US.

Watkiss P, Hunt A, Blyth W, Dyszynski J. 2015. The use of new economic decision support tools for adaptation assessment: A review of methods and applications, towards guidance on applicability. *Climatic Change* 132(3): 401–416. Retrieved from http://dx.doi.org/10.1007/s10584-014-1250-9

Watson CS, White NJ, Church JA, King MA, Burgette RJ, Legresy B. 2015. Unabated global mean sea-level rise over the satellite altimeter era. *Nature Climate Change* 5(6): 565–568. Retrieved from http://dx.doi.org/10.1038/nclimate2635.

Watts RH. 2011. The Christchurch waterways story. Landcare Research Science Series No. 38: 51. Lincoln: Manaaki Whenua Press. Retrieved from www.landcareresearch.co.nz/publications/researchpubs/LRSS-38.pdf

Werner AD, Simmons CT. 2009. Impact of sea-level rise on sea water intrusion in coastal aquifers. *Ground Water* 47(2): 197–204.

Werners SE, Pfenninger S, van Slobbe E, Haasnoot M, Kwakkel JH, Swart RJ. 2013. Thresholds, tipping and turning points for sustainability under climate change. *Current Opinion in Environmental Sustainability* 5(3–4): 334–340. Retrieved from http://dx.doi.org/10.1016/j.cosust.2013.06.005.

Wild M, Walsh J, Walters R, Duncan M. 2004. *Buller River storm surge and river flooding analysis. NIWA Client Report CHC2004-048*. Prepared for Buller District Council by NIWA. Wellington: NIWA.

Wise RM, Fazey I, Smith MS, Park SE, Eakin HC, Van Garderen EA, Campbell B. 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change* 28:325-336.

Wiseman J, Williamson L, Fritze J. 2010. Community engagement and climate change: Learning from recent Australian experience. *International Journal of Climate Change Strategies and Management* 2(2) 134–147. doi: 10.1108/17568691011040399.

World Meteorological Organization. 2007. The role of climatological normals in a changing climate. WMO/TD No. 1377.

Wyncoll D, Gouldby B. 2015. Integrating a multivariate extreme value method within a system flood risk analysis model. *Journal of Flood Risk Management* 8(2): 145–160.

Young IR, Vinoth J, Zieger S, Babanin AV. 2012. Investigation of trends in extreme value wave height and wind speed. *Journal of Geophysical Research-Oceans* 117: C00J06. doi: 10.1029/2011JC007753.

Zhang X, Church JA. 2012. Sea level trends, interannual and decadal variability in the Pacific Ocean. *Geophysical Research Letters* 39(21): L21701. Retrieved from http://dx.doi.org/10.1029/2012GL053240.